“Bio-Medical Technology Foresights”

Spring 2010

Special Lectures on Agricultural Biotechnology

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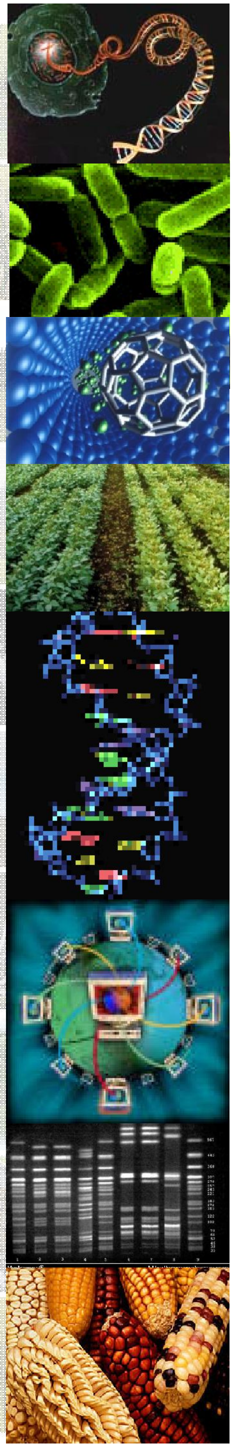


Special Lectures on Agricultural Biotechnology

Summary

Brief Introduction to Agriculture

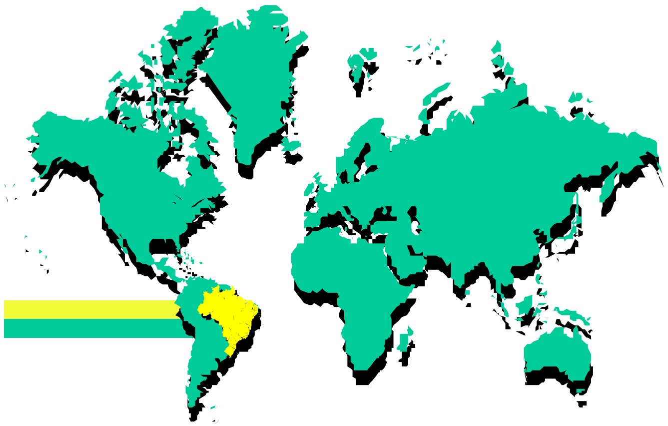
Agriculture and Sustainable Development

Biotechnology and Agricultural Innovation

Agriculture… Industry of the Future?

Agriculture, Bioindustry and Bioeconomy

Introduction

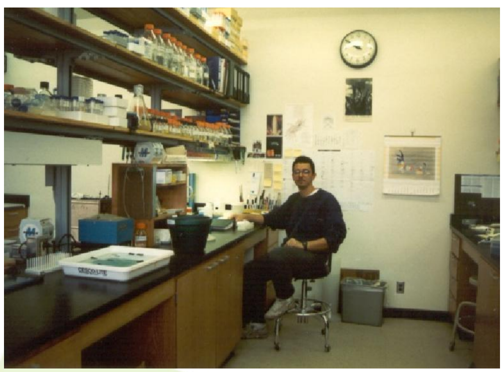


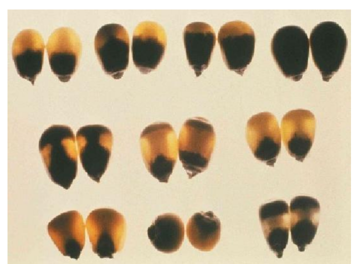
Labex Korea

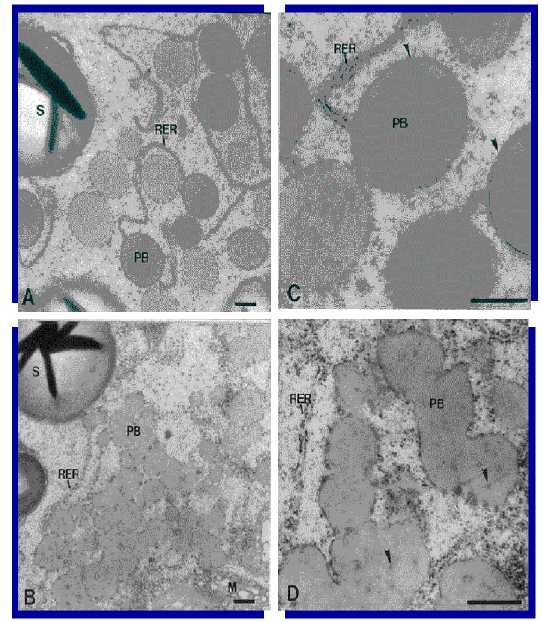
Korea-Brazil Summit (11.2008)

Inauguration of Labex Korea (12.2009)

Introduction





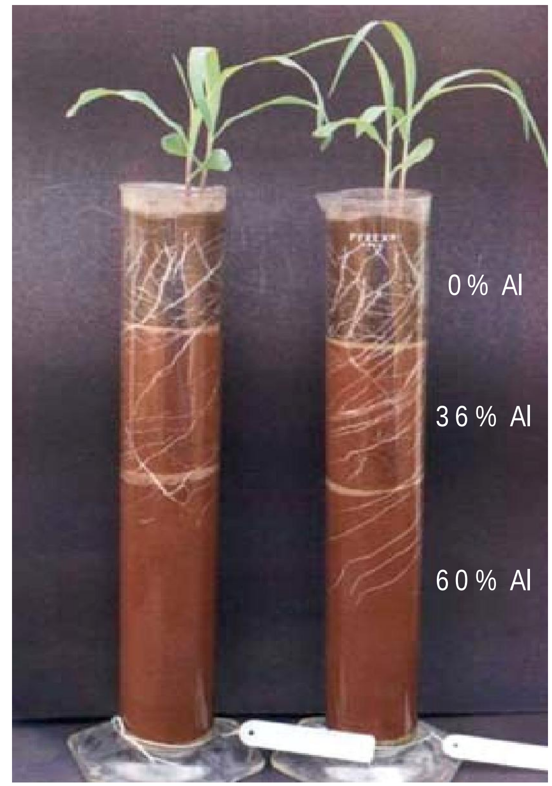


PNAS 94:7094-7097

Introduction

Aluminum tolerance and phosphorus use efficiency – Adapting corn to the Brazilian Savannahs

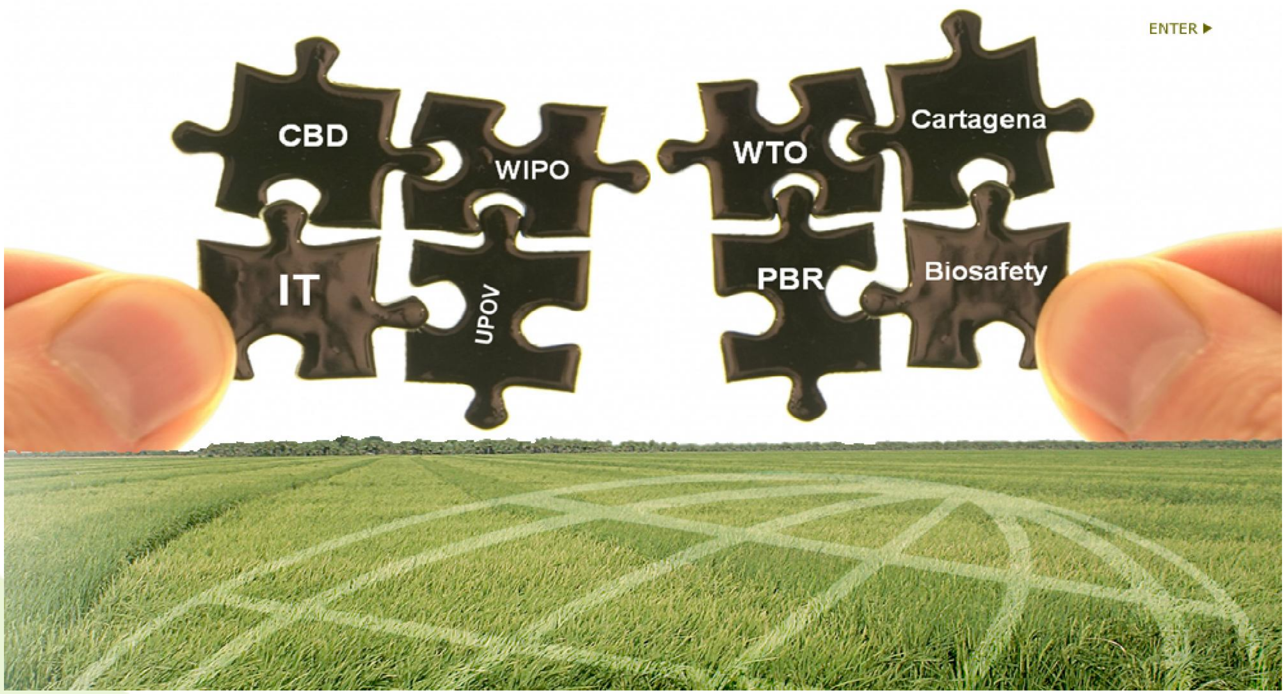
ACIDITY SUSCEPTIBLE ACIDITY TOLERANT



Introduction

GIPB
Global Partnership Initiative for Plant Breeding Capacity Building

Knowledge Tools on Policies and Regulations
Affecting Access and Use of Biological Resources



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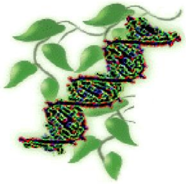
Before we start…

Why "Agriculture" in a Bio-Medical Technology Foresights Course?

Why Agriculture in a Bio-Medical Technology Foresights Course?

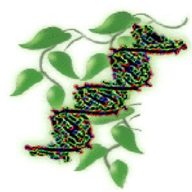
Food – Nutrition – Health



Why Agriculture in a Bio-Medical Technology Foresights Course?

Food – Nutrition – Health

Agriculture – Environment – Sustainability – Well being

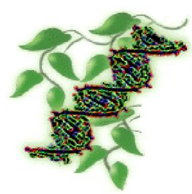


Why Agriculture in a Bio-Medical Technology Foresights Course?

Food – Nutrition – Health

Agriculture – Environment – Sustainability – Well being

Food – Fiber – Feed – Fuels – Pharma



Why Agriculture in a Bio-Medical Technology Foresights Course?

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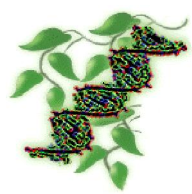
Food – Fiber – Feed – Fuels – Pharma

Agriculture – Bioindustry – Bioeconomy



A few definitions…

Biotechnology

A word that has a range of meanings and connotations…

CBD* Definition of Biotechnology

"Any technological application that uses biological systems, living organisms, or derivatives thereof, to make or modify products or processes for specific use."

*The Convention on Biological Diversity (Article 2. Use of Terms). United Nations. 1992.

Biotechnology

A word that has a range of meanings and connotations…

Traditional or Classic Definition of Biotechnology

First used in 1917 * to describe the use of technologies based on living systems (plants, animals, or microbes) to develop commercial processes and products or to improve existing species.

Beer making , Wine making, Bread making, Cheese making…
Conventional breeding of crops and animals…

* Source: Robert Bud, The Uses of Life. A History of Biotechnology, Cambridge: Cambridge University Press, 1993.

Biotechnology and Agriculture

Modern Biotechnology

The application of recombinant DNA techniques, biochemistry, molecular and cellular biology, genetics, genetic engineering and related disciplines* to improve plants and animals, to develop microorganisms for specific uses or to transform biological systems into useful processes and products.

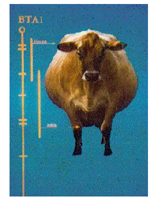
*** Cell culture, genomics, molecular marker-assisted selection, molecular breeding, cloning, gene technology (genetic modification), information technology (bioinformatics), etc.**

Biotechnology and Agriculture

GENETIC ENGINEERING

TRANSGENIC TECHNOLOGY

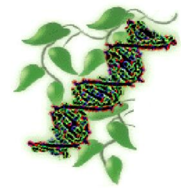
Biotic Stress Tolerance
Abiotic Stress Tolerance
Quality/Functionality
New Bioproducts

MOLECULAR MARKERS

MOLECULAR MAPS

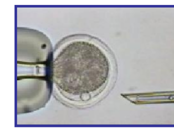
Gene/Trait Mapping
Genetic Resources Charc.
Function Characterization
Molecular Breeding



GENOMIC SCIENCES

GENOMICS
PROTEOMICS

Coffee
Eucalyptus
Banana/Rice
Bovine & Others




ADV. ANIMAL PRODUCTION

CLONING
IN-VITRO FERTILIZATION

Animal Breeding
GR Conservation
Germplasm Enhancement
Biofactories

GENETICS, PHYSIOLOGY, TISSUE CULTURE, BIOINFORMATICS, BIOSAFETY, ETC...

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Brief Introduction to Agriculture

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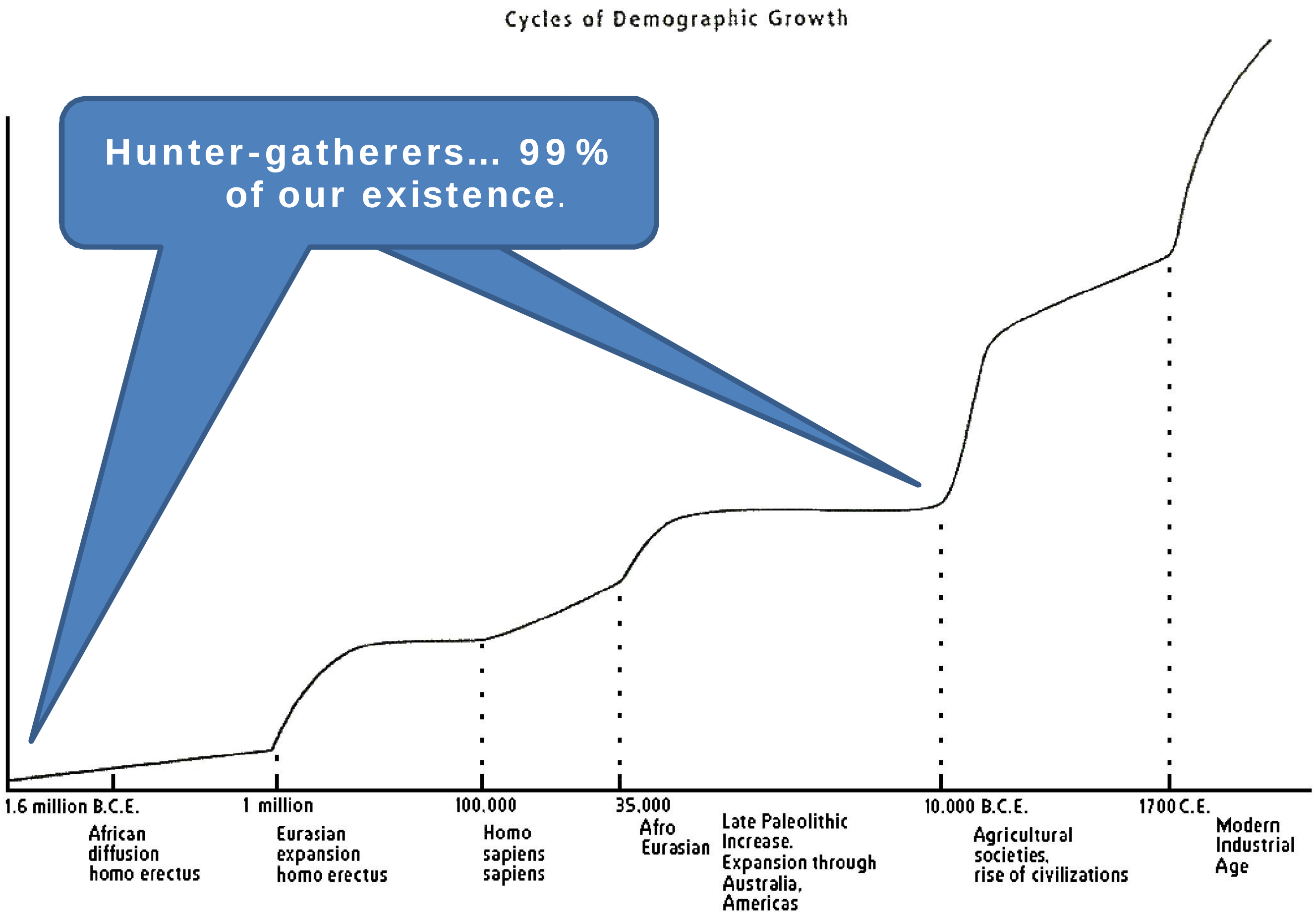
A Brief Introduction to Agriculture

Agriculture, also known as farming…

…is the production of food, feed, fiber and other goods by the systematic use of land to growing and harvesting of plants and animals.

…a key development that led to the rise of human civilization.

A Brief Introduction to Agriculture



Human population growth rate increased slowly:

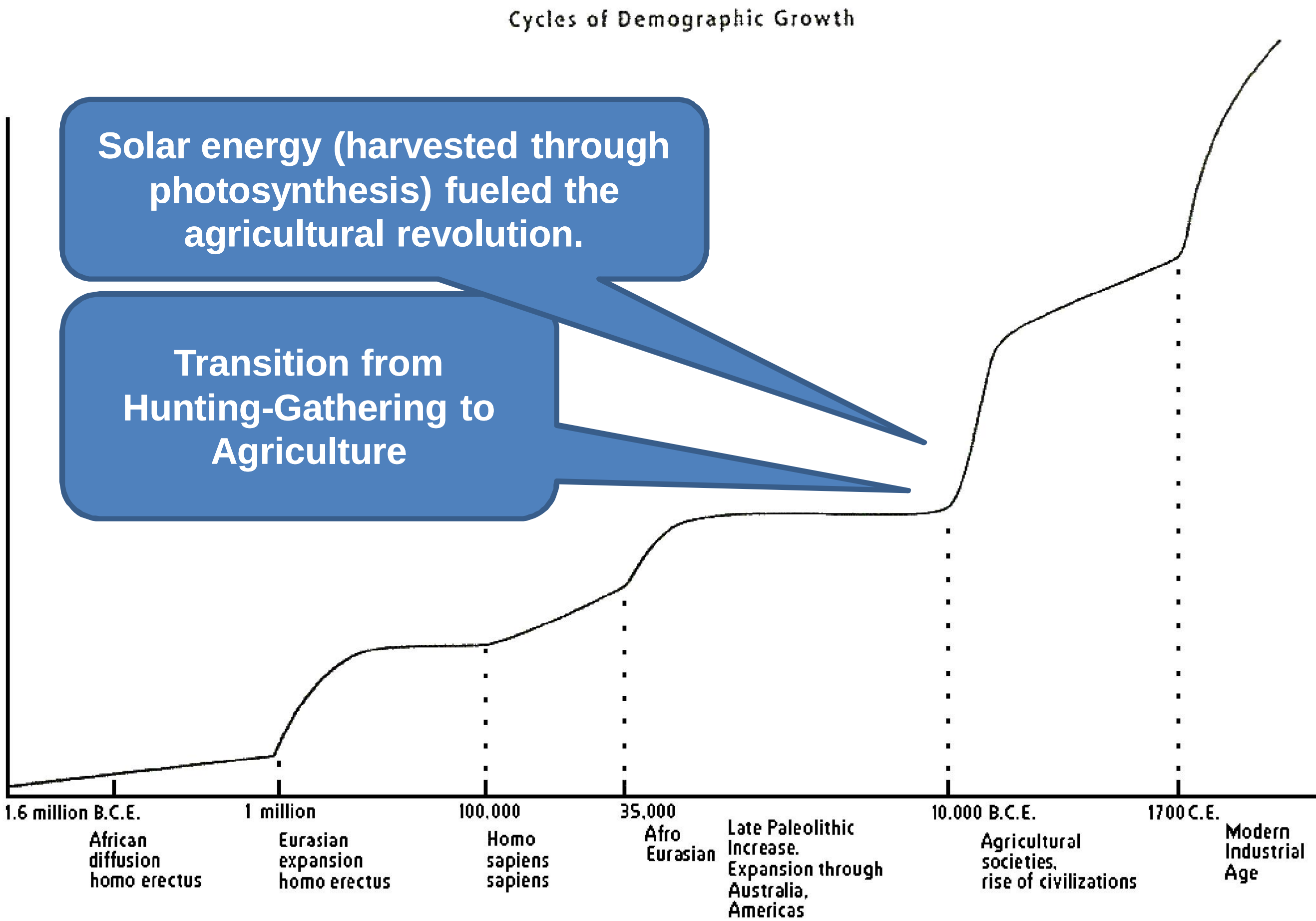
.0007-.0020 % /yr. Pleistocene age, up to 12 000 years BP

.1 % /yr. Neolithic

Low birth rate attributed to lifestyle of hunter-gatherer

Modified from http://www.hort.purdue.edu/newcrop/history/default.html

A Brief Introduction to Agriculture

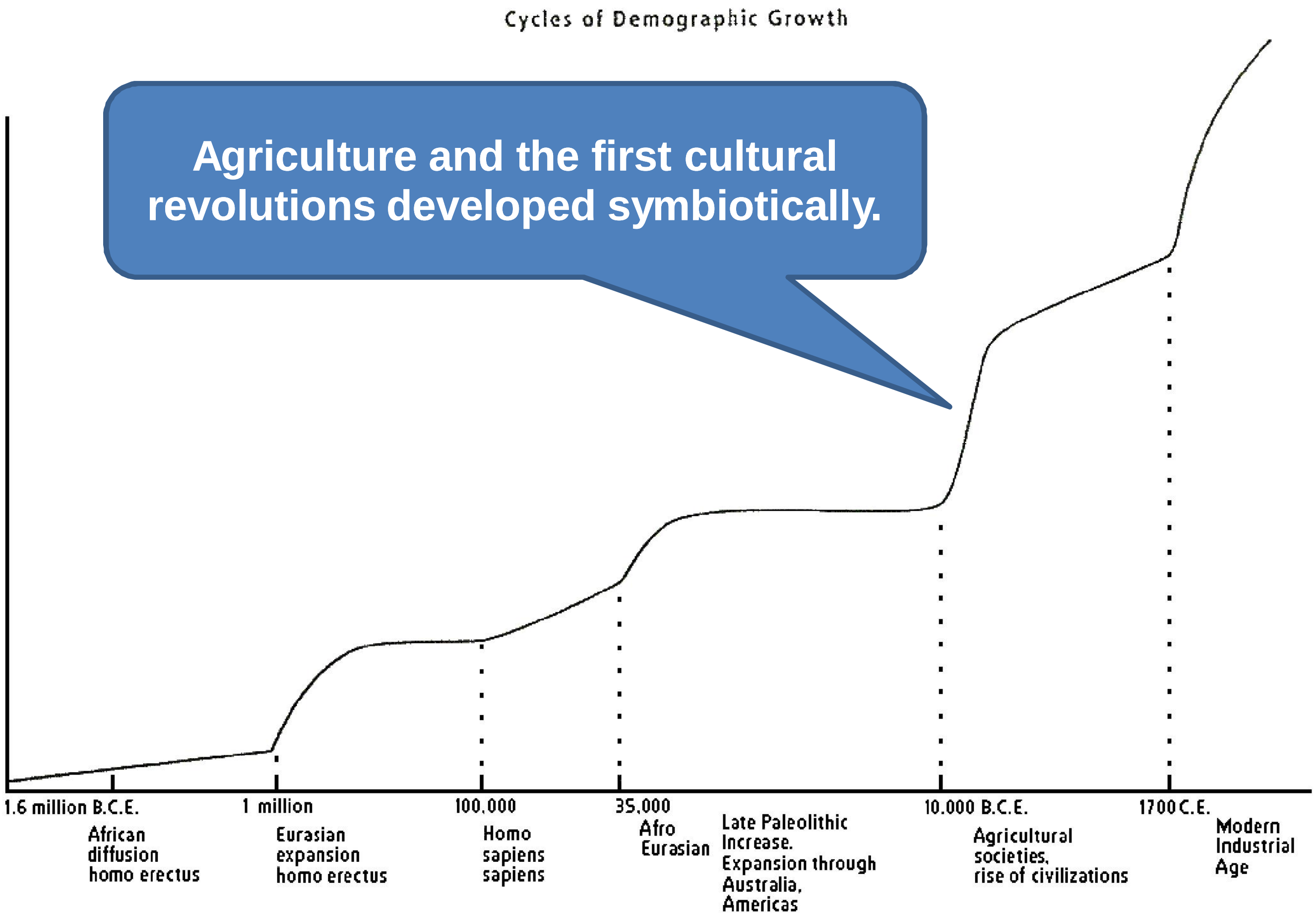


Social groups of hunters/gatherers made a slow transition into a more settled lifestyle, closely associated with the regular cultivation of plants, especially cereals.

Crop plants and animals brought under human management ('domestication')

Modified from http://www.hcs.ohio-state.edu/hcs/tmi/hcs210/hortorigins/NEOrigins.html

A Brief Introduction to Agriculture



Neolithic Revolution

Various Locations

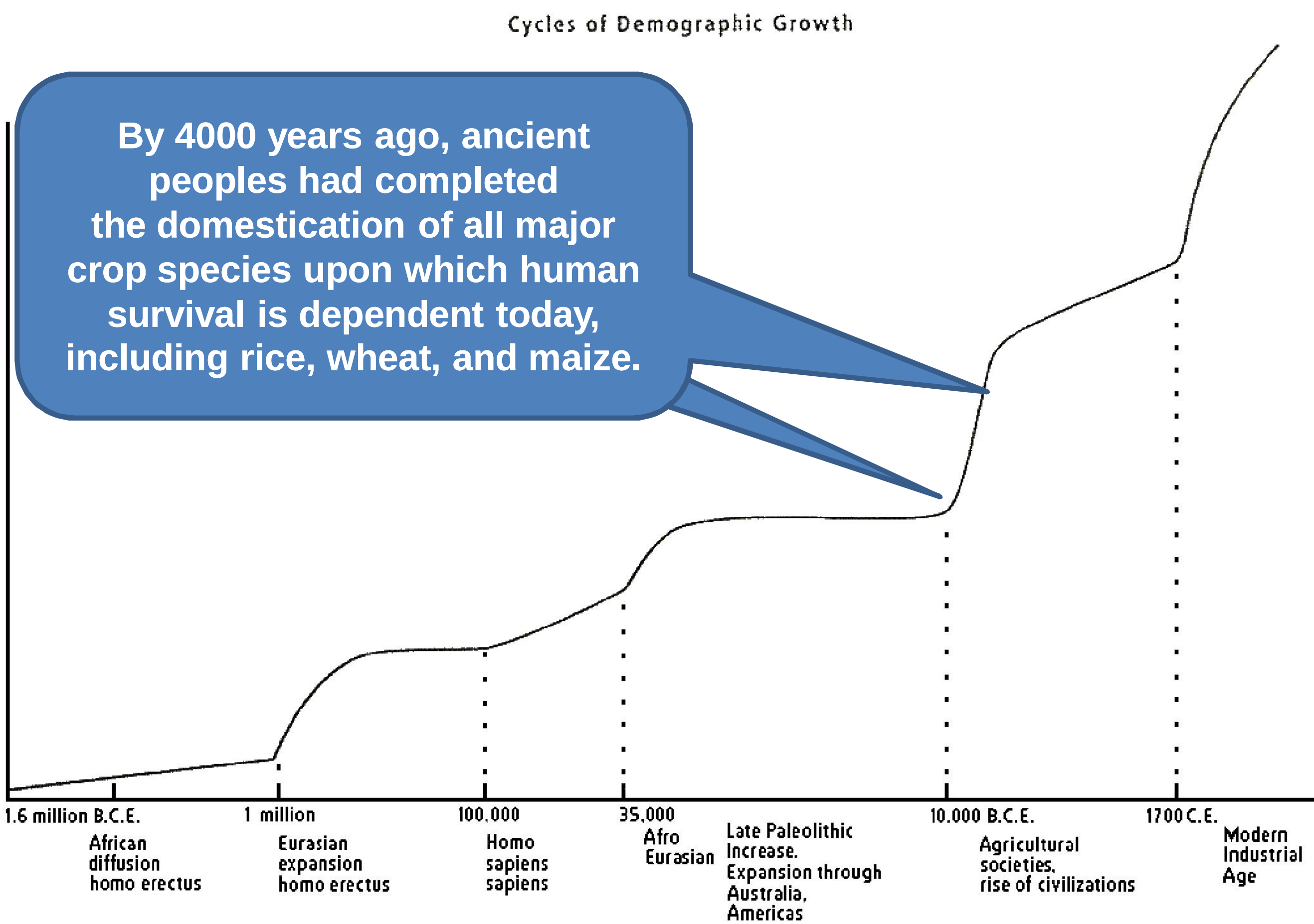
Fertile Crescent
Indus Valley
China
Americas

Increasing Importance of Plants

Food
Fuel
Weapons
Ritual
Clothing
Medicine

Modified from http://www.hort.purdue.edu/newcrop/history/default.html

A Brief Introduction to Agriculture



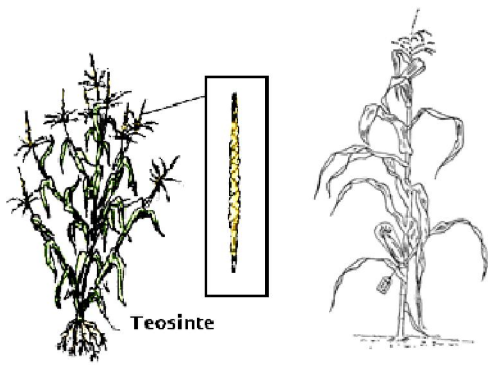
By 4000 years ago, ancient peoples had completed the domestication of all major crop species upon which human survival is dependent today, including rice, wheat, and maize.

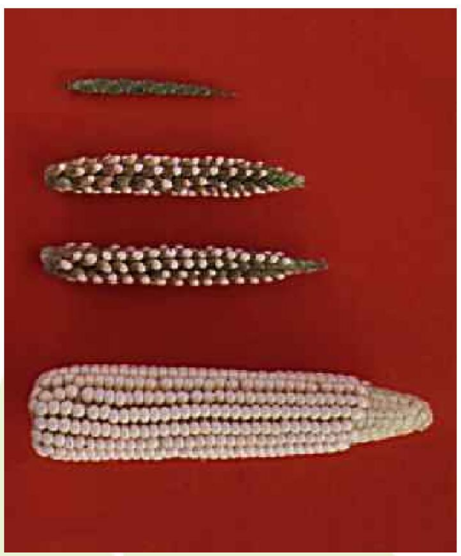
For many crops, domestication has rendered the plant completely dependent on humans

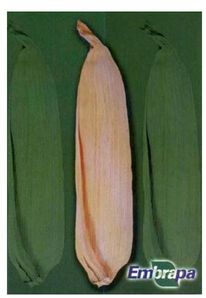
Many domesticated crops are no longer capable of self-propagating in nature.

Source: Doebley, J.F., Gaut, B.S., Smith, B.D. 2006. The molecular genetics of crop domestication.

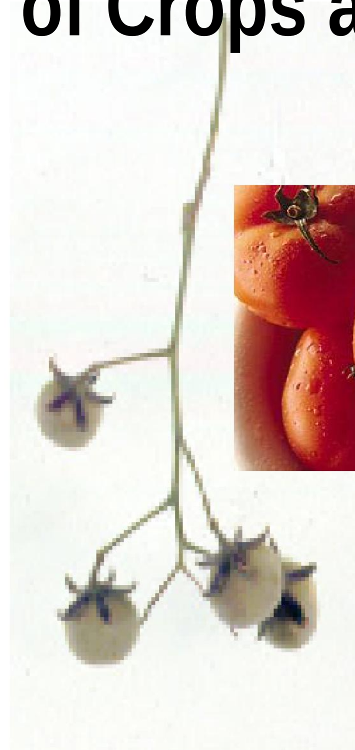
Domestication of Crops and Animals







Corn



Tomato

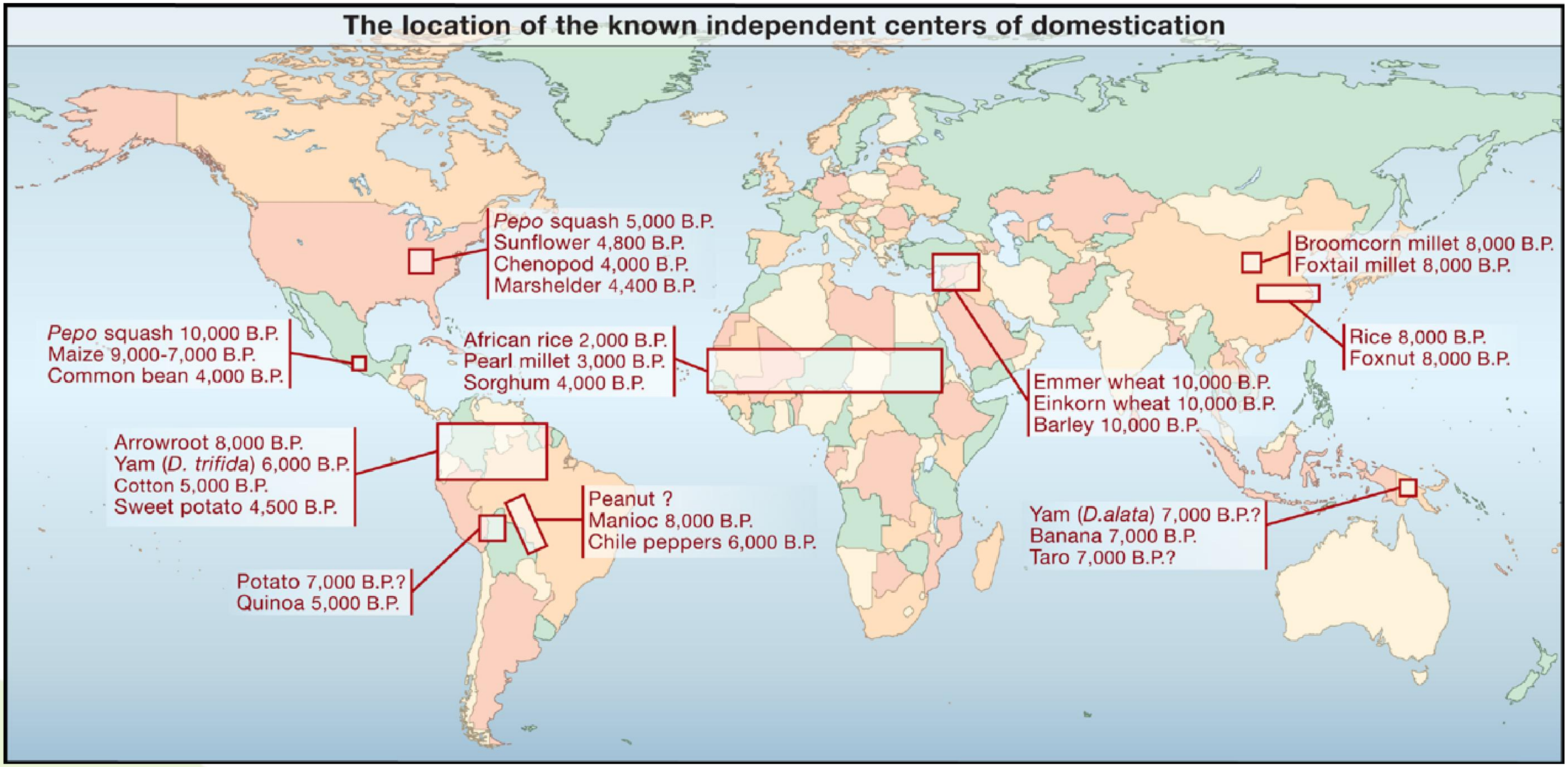
Dog

A Brief Introduction to Agriculture

"Crops are artifacts made and molded by man as much as a flint arrowhead, a stone ax-head, or a clay pot."

Harlan, J. R. 1975. Crops and Man. Amer. Soc. Agron., Madison, Wisconsin.

A Brief Introduction to Agriculture



Crop plants and estimates of when they were brought under domestication based on currently available archaeological evidence.

Source: Doebley, J.F., Gaut, B.S., Smith, B.D. 2006. The molecular genetics of crop domestication.

A Brief Introduction to Agriculture

N. I. Vavilov (1887-1943)

Centers of Origin of Cultivated Plants (1926)

Specific geographic origin of major cultivated plants defined

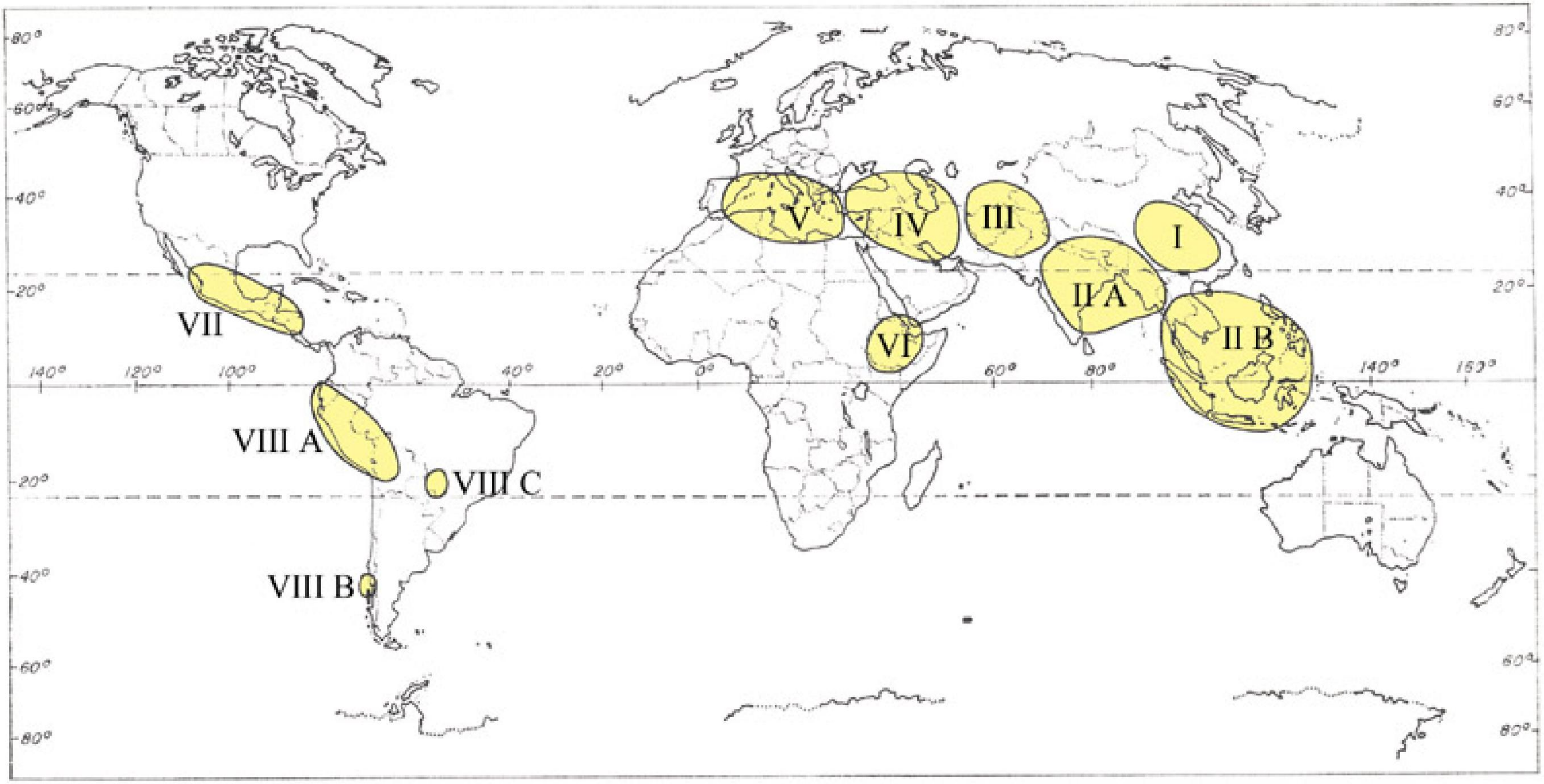
8 Primary world centers

640 species listed
5/6 Old World;
1/6 New World

Source: http://www.hort.purdue.edu/newcrop/history/default.html

A Brief Introduction to Agriculture

Centers of Origin of Crop Plants



The eight Vavilovian Centers of Origin for crop plants.

Source: http://www.hort.purdue.edu/newcrop/history/default.html

A Brief Introduction to Agriculture

The centers of origin are important sources of wild relatives of crop plants…

Source:
http://www.ers.usda.gov/Amberwaves/june03/Features/PlantGeneticResources.htm

A Brief Introduction to Agriculture

Wild relatives of crop plants can provide plant breeders and biologists with useful traits (genes), such as resistance to diseases and pests and tolerance to abiotic stresses.

In fact, many of the improved varieties of crop plants carry traits obtained from wild relatives

Introduced through selective breeding.

Source:
http://www.ers.usda.gov/Amberwaves/june03/Features/PlantGeneticResources.htm

A Brief Introduction to Agriculture

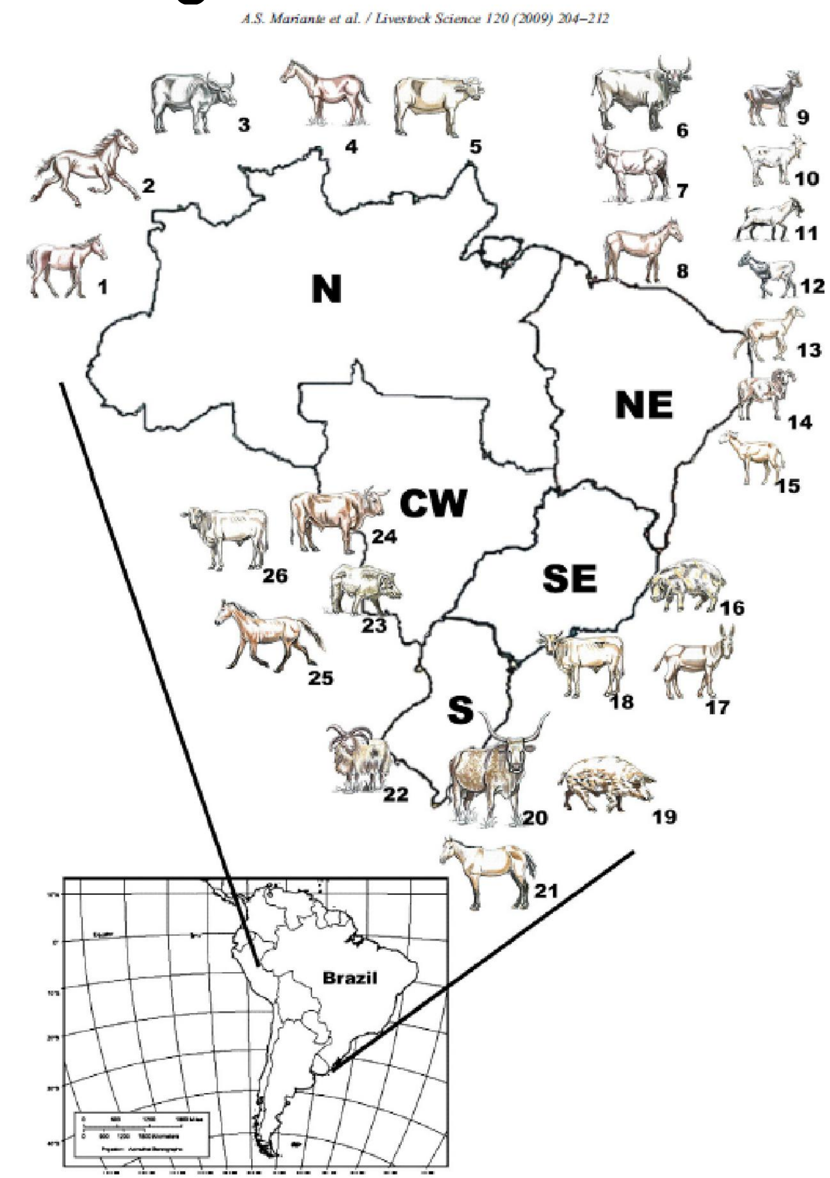
Naturalization of Livestock

The case of Brazil

Most livestock are not indigenous to Brazil;

Periodic introductions resulted in a wide range of genetic diversity that, for centuries, supported domestic animal production in the country;

Natural selection → adaptation to biotic and abiotic pressures;

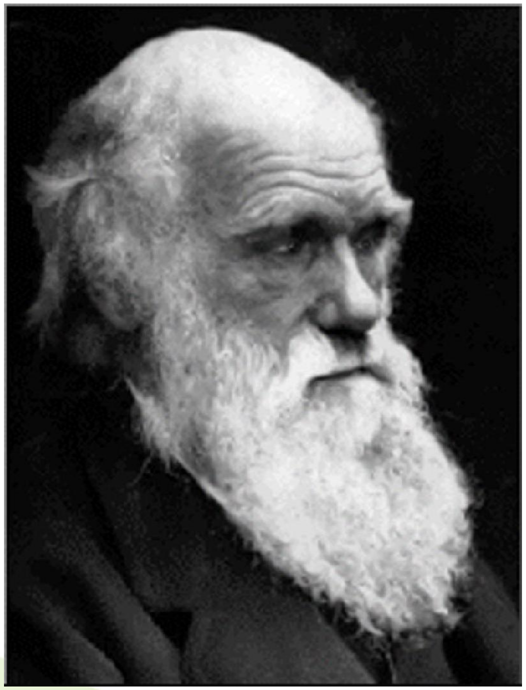


Source: Embrapa, Brazil

A Brief Introduction to Agriculture

From ancient to modern agriculture…

A Brief Introduction to Agriculture



Charles Darwin (1809-1882)

On the Origin of the Species (1859) establishing the Theory of Evolution and its mechanism, natural selection...

Concepts of Darwinism

Evolution occurs; species not fixed in time...

Evolutionary change gradual

Primary mechanism is struggle for existence and survival of the fittest

All species arose from a single original life form

Modified from: http://www.hort.purdue.edu/newcrop/history/default.html

A Brief Introduction to Agriculture

Gregor Mendel (1822-1884)
"Father of Genetics"

The age of genetics begins when Gregor Mendel outlines the basic laws of heredity, that still hold true today for all organisms

Crosses peas, intercrosses progeny, classifies and counts segregation of traits

Paper of 1866 formulates the "Laws of Genetics" concerning transmission of genetic information

Law of Segregation and the Law of Independent Assortment.

Modified from: http://www.hort.purdue.edu/newcrop/history/default.html

A Brief Introduction to Agriculture

Mendel´s Laws were rediscovered in 1900 leading to a tremendous development in the field of genetics, including the development of Quantitative Genetics

The study of continuous traits (such as height or weight) and their underlying mechanisms.

It is effectively an extension of simple Mendelian inheritance in that the combined effect of the many underlying genes results in a continuous distribution of phenotypic values.

The phenotypic value (P) of an individual is the combined effect of the genotypic value (G) and the environmental deviation (E)

$$P = G + E$$

The genotypic value is the combined effect of all the genetic effects, including nuclear genes, mitochondrial genes and interactions between the genes.

A Brief Introduction to Agriculture

Genetics and Plant Breeding

The knowledge of genetics has transformed plant breeding in a scientific discipline

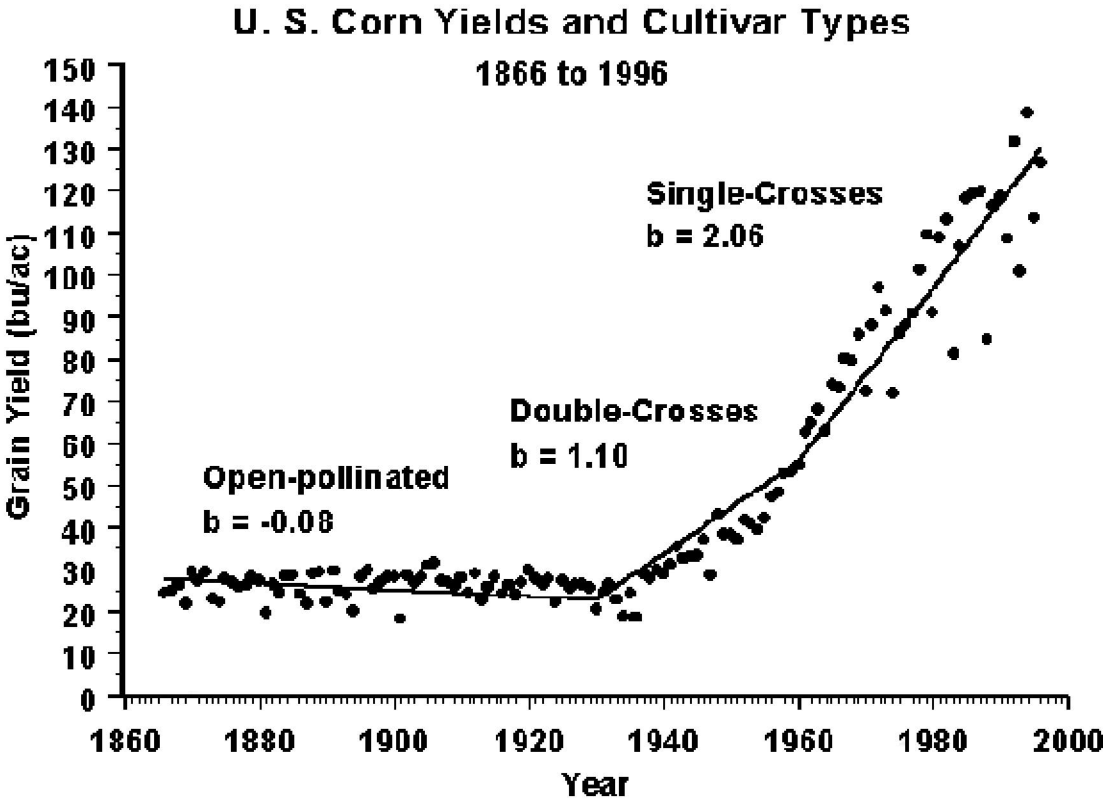
Classical genetics has demonstrated how segregation of different traits through sexual recombination can produce new combination of organisms

The key is genetic segregation plus selection…

The science of genetics had a profound effect on plant breeding and agriculture in the 20th century

- Hybrid corn
- Breeding for disease resistance
- Adaptation to environmental stresses
- Genetics of male sterility (non-nuclear inheritance)

A Brief Introduction to Agriculture



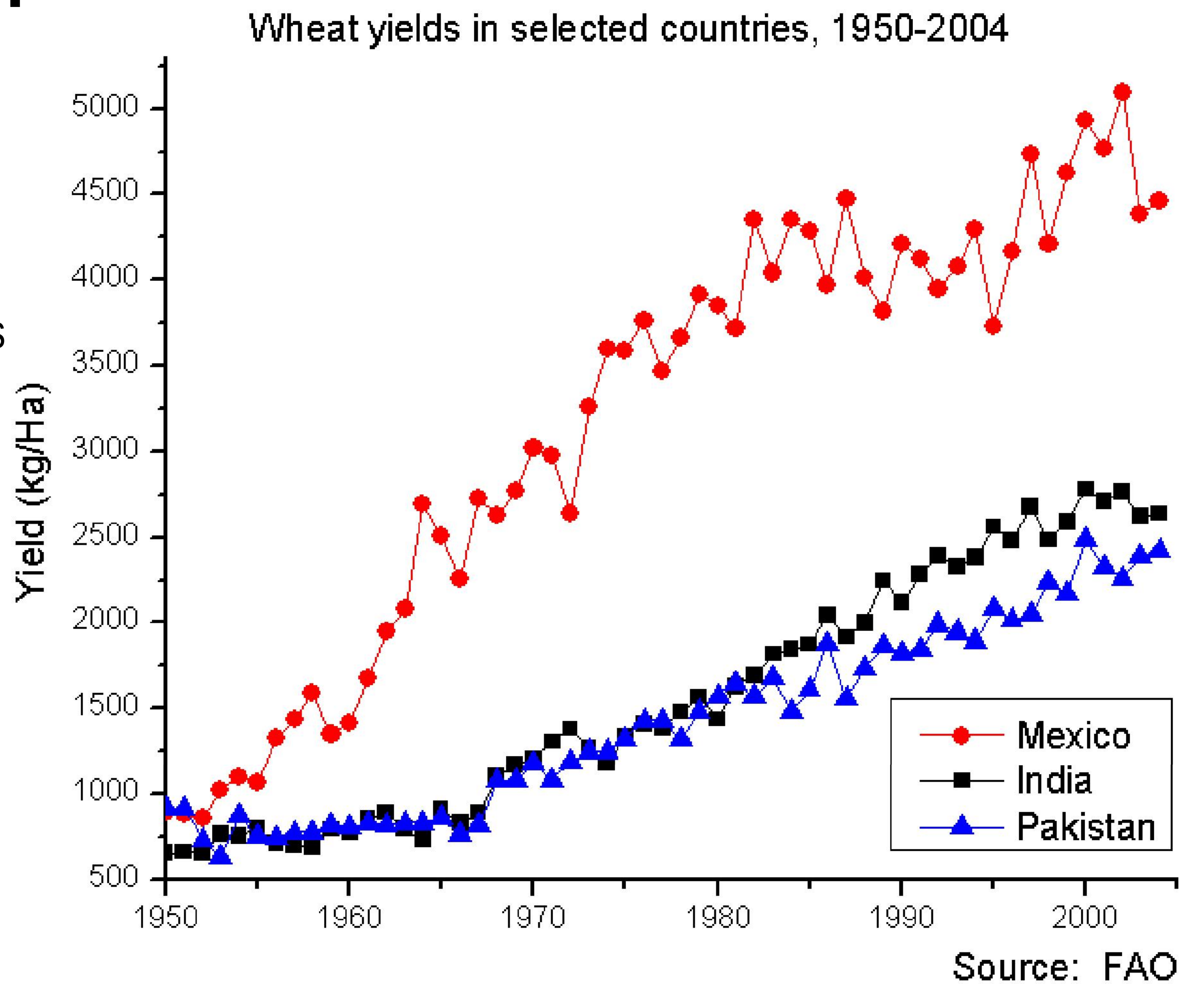
Source: http://www.ag.ndsu.nodak.edu/plantsci/breeding/corn/index_files/image004.gif

“Green Revolution”

During the mid-20th century, Norman Borlaug led the introduction of high-yielding varieties combined with modern agricultural production techniques to Mexico, Pakistan, and India.

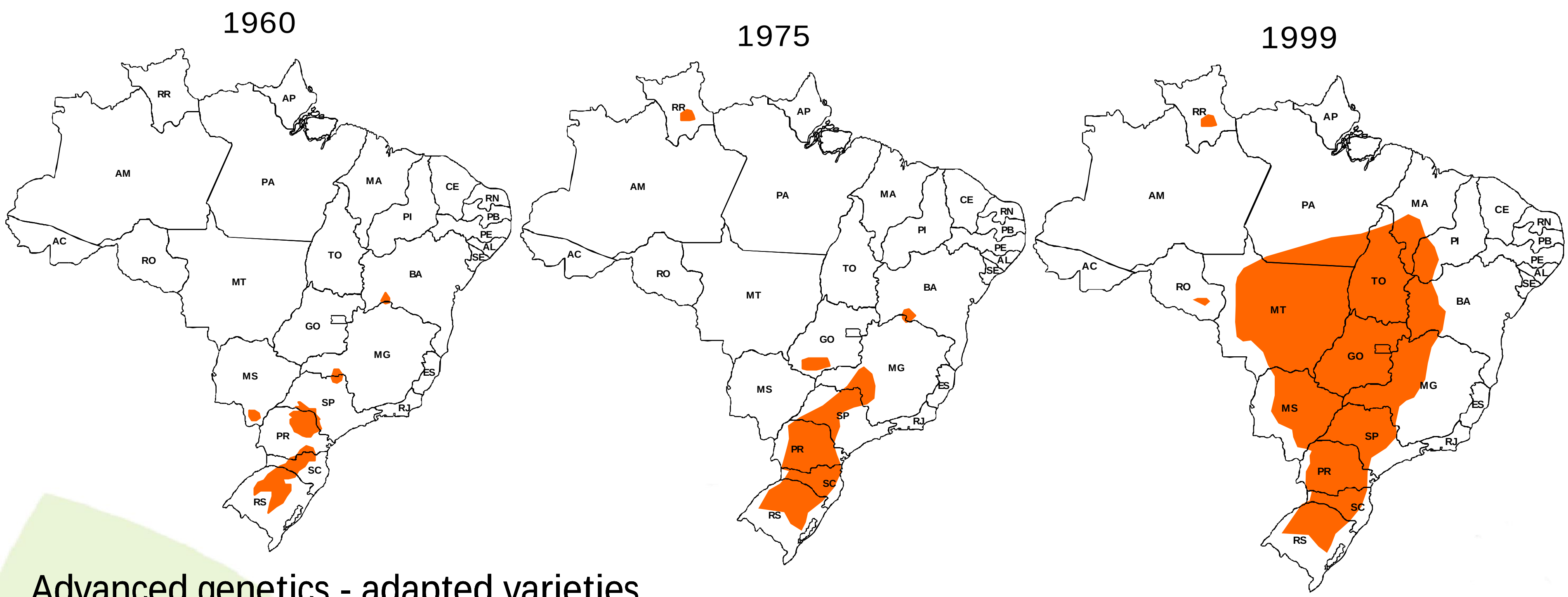
As a result, Mexico became a net exporter of wheat by 1963. Between 1965 and 1970, wheat yields nearly doubled in Pakistan and India, greatly improving the food security in those nations.

These collective increases in yield have been labeled the “Green Revolution”



Tropical soybeans

Technological evolution and crop expansion in Brazil



Advanced genetics - adapted varieties

Biological nitrogen fixation

Minimum tillage - mechanization

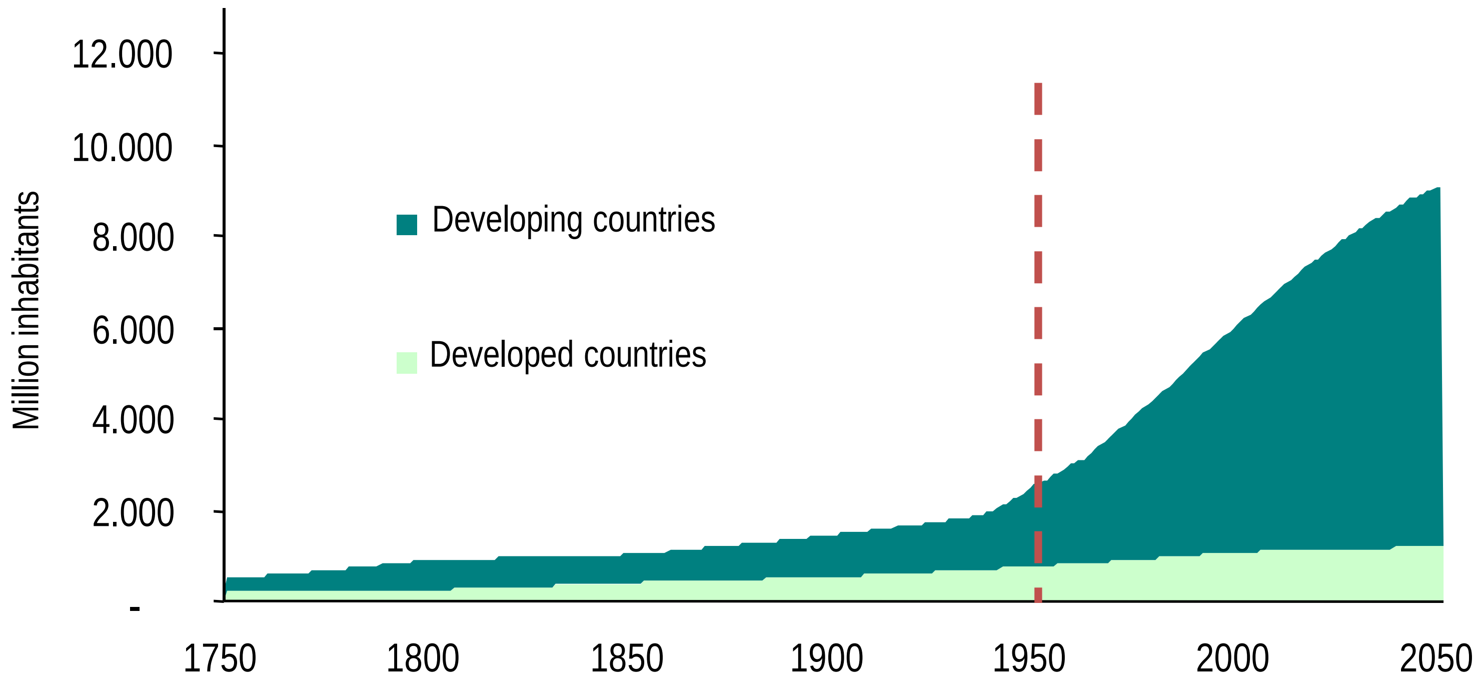
Source: Embrapa Soybean

Tropical soybeans

Technological evolution and crop expansion in Brazil

Source: Embrapa Soybean

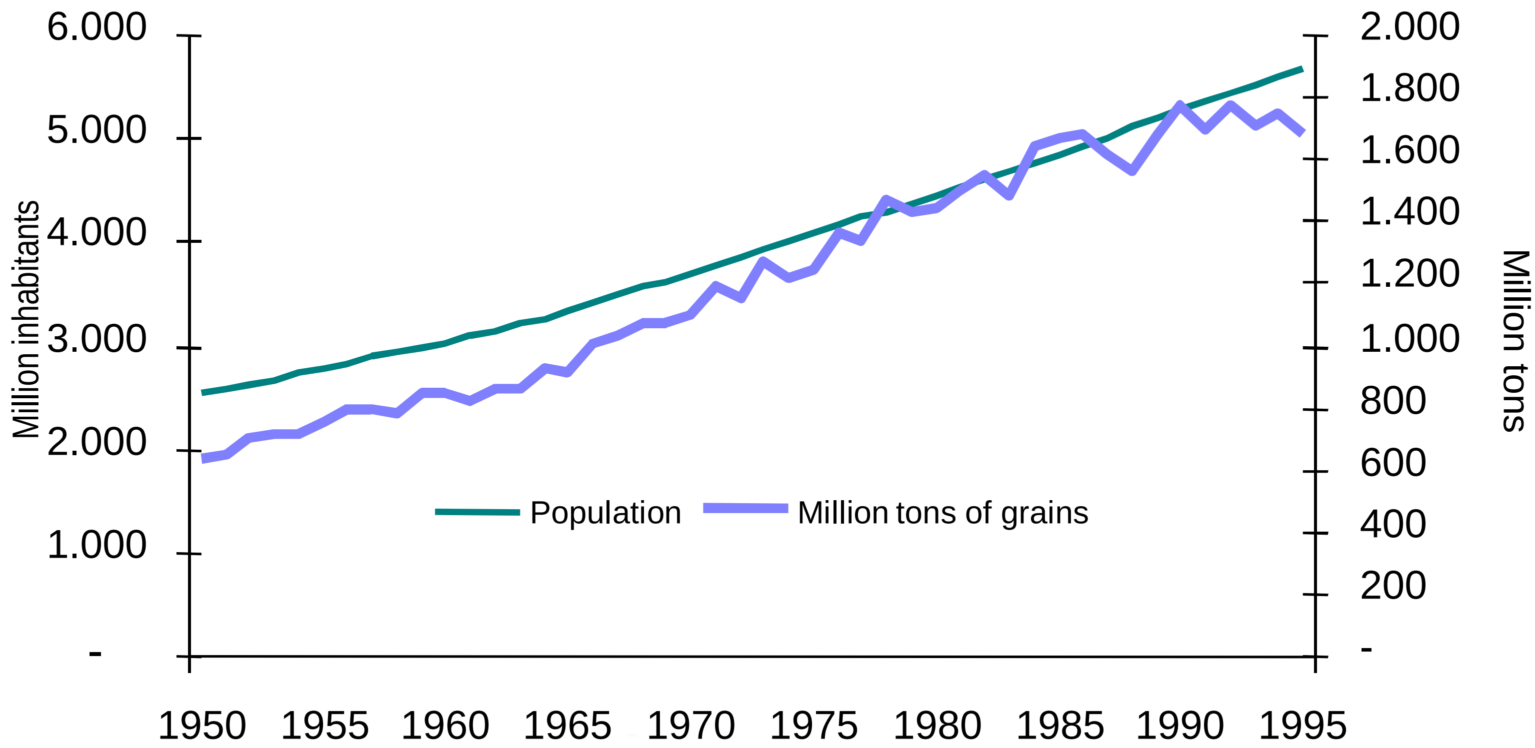
Agriculture and Population Growth



In the early 1800s the population of the world was estimated to be around 1 billion. It grew to 2 billion in the 1920s and to 6 billion at the end of the last millennium. Currently, approximately 80 million people are added to the world population per year

Source: Pimentel and Pimentel, 2000

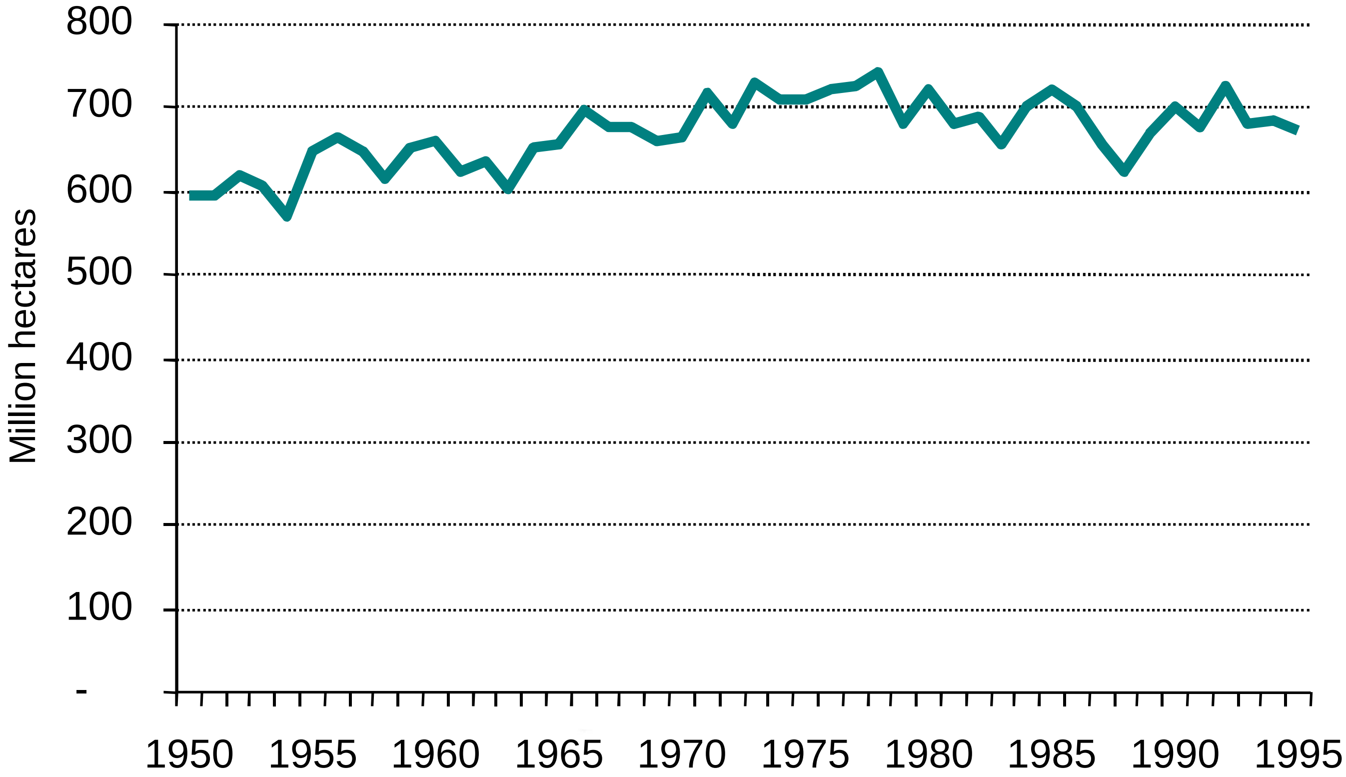
Agriculture and Population Growth



Widespread hunger was avoided by proportional increases in food production

Source: Reinach , 2003

Agriculture and Population Growth



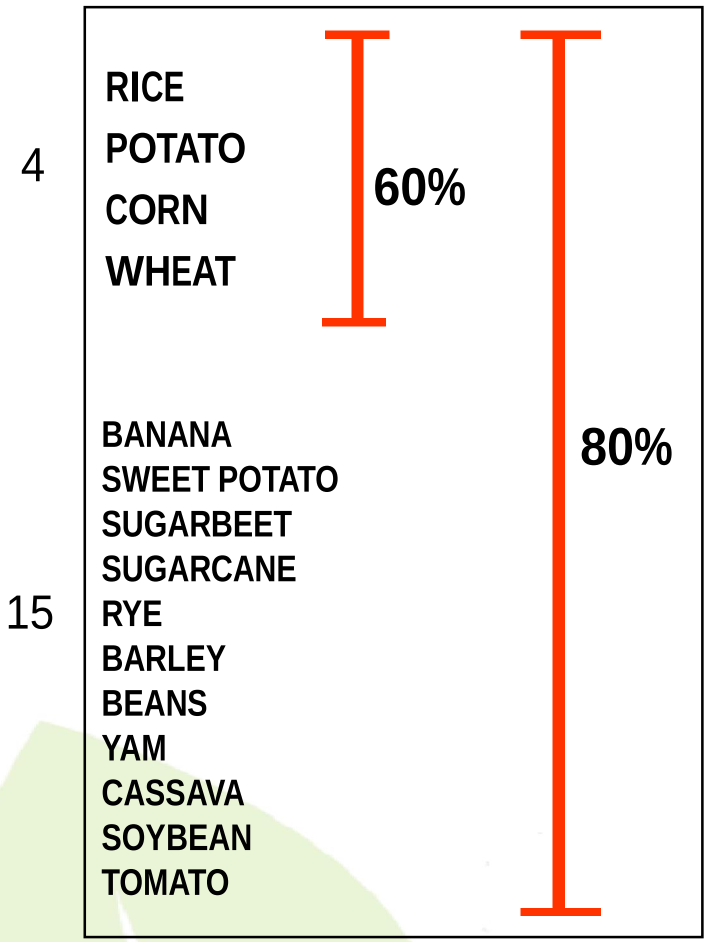
The increase in food production have not caused more impacts in the ecossystems due to incorporation of technologies that allowed increased yields and reduced increases in cultivated areas.

Source: Reinach , 2003

A Brief Introduction to Agriculture

Despite its contributions, modern agriculture is associated to many vulnerabilities…

Vulnerabilities



Source: FAO

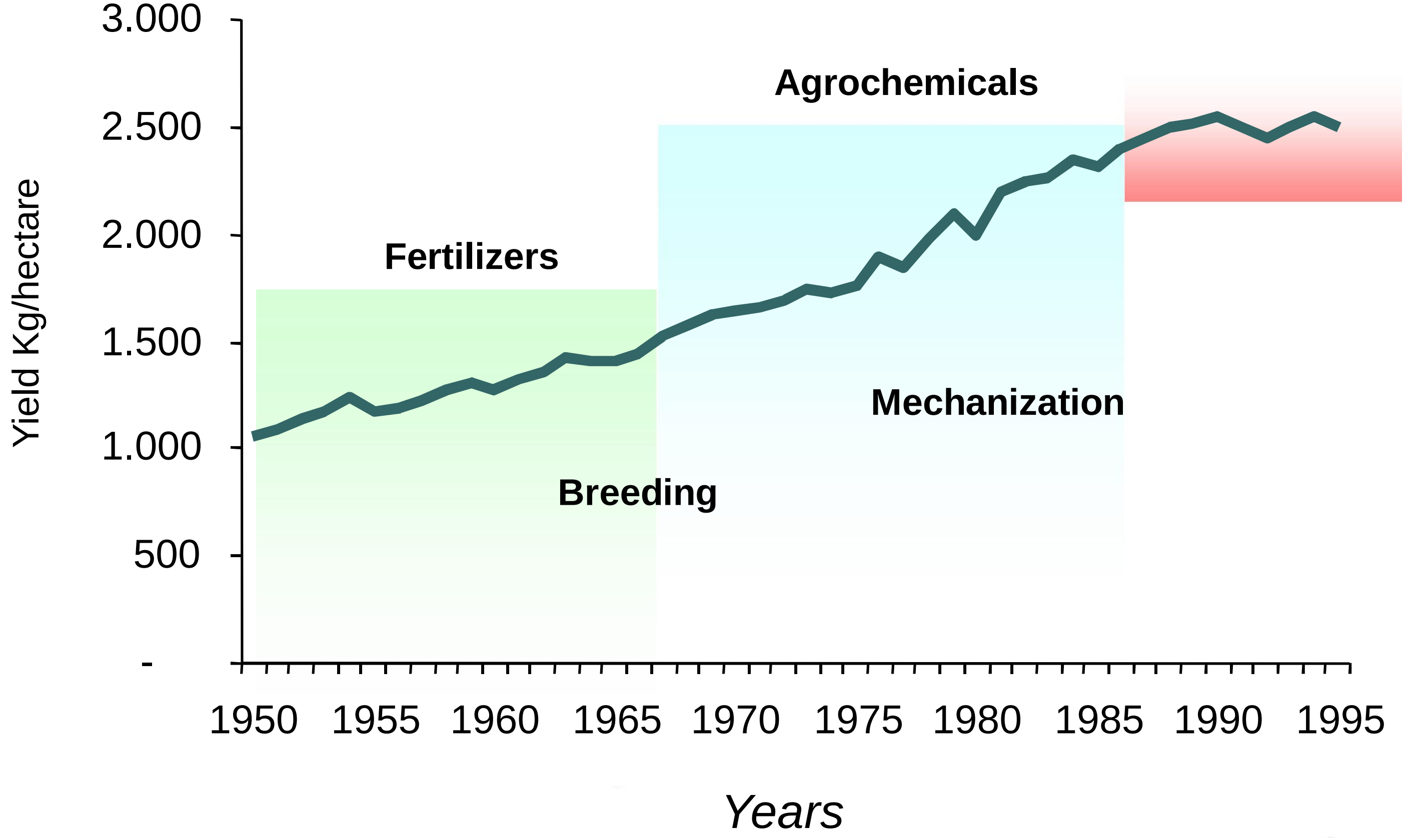
The world population is relying on a limited number of crop species;

Insuficient diversity of human diets;

At the same time new challenges require new functionalities from agriculture…

Food, feed, fiber, fuels…
Food, nutrition and health
New bioeconomy and "green growth"

Vulnerabilities



As we face increasing world population, shortage of natural resources and climatic change, farming technologies are clearly showing signs of fatigue…

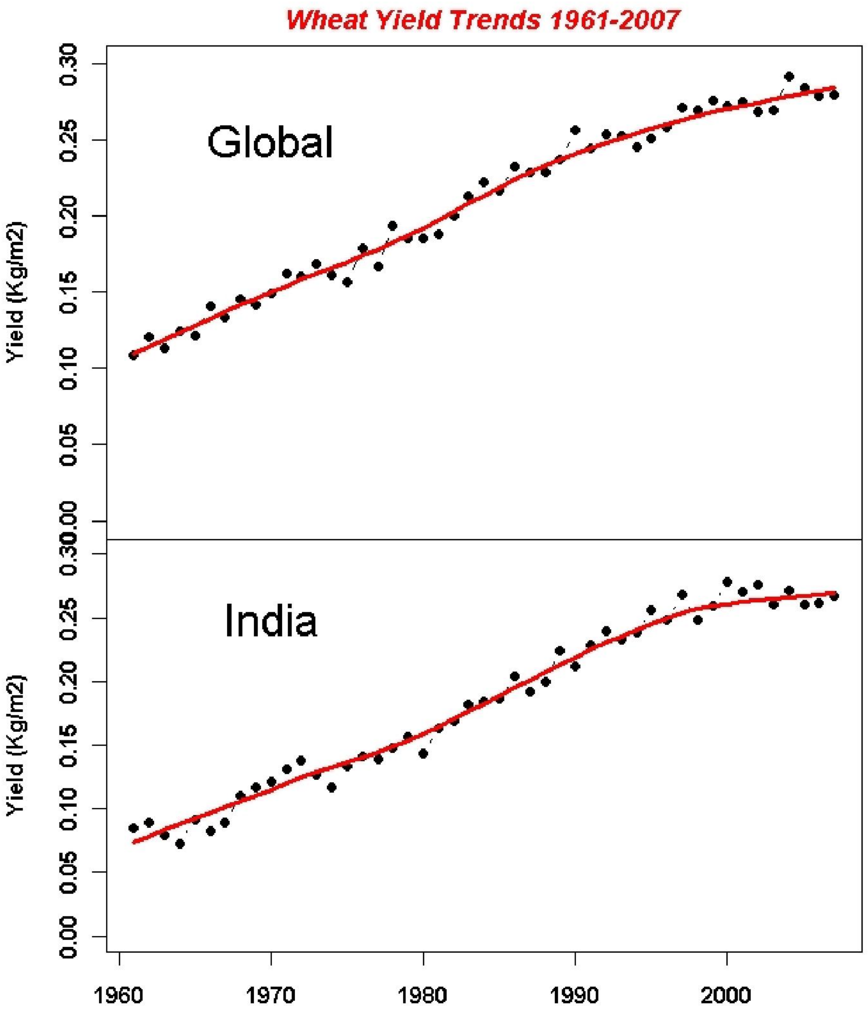
Source: World Bank; Reinach , 2003

Vulnerabilities

"Green Revolution Fatigue"

Resource constraints (on crop yields, land area, water, etc) are already impacting agriculture.

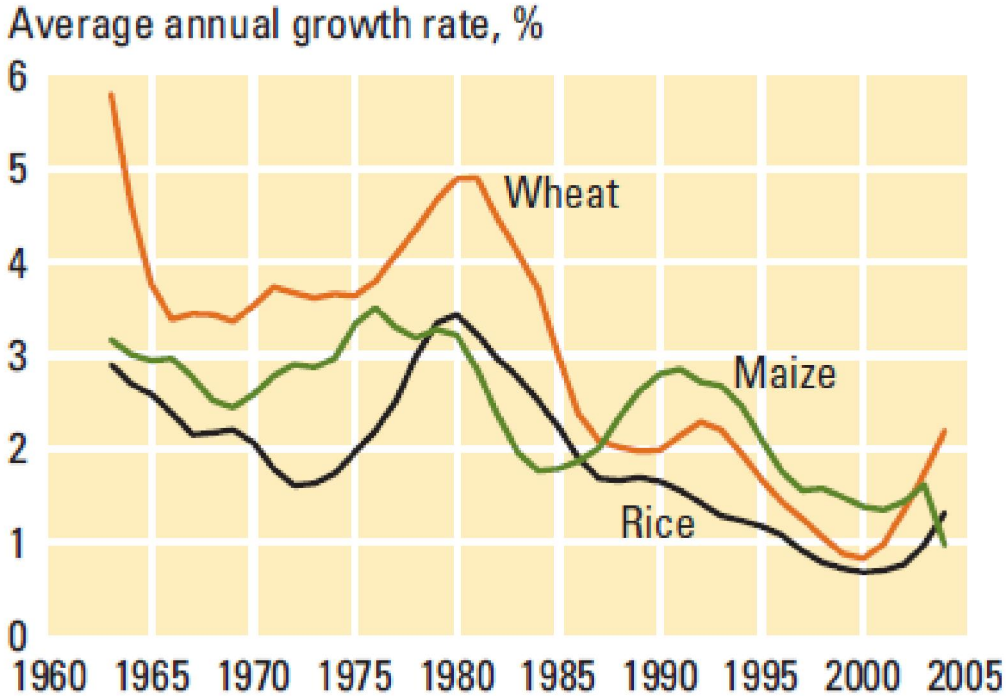
FAO data shows that the rate of wheat yield growth is slowing and may be saturating.



http://faostat.fao.org/site/567/default.aspx#ancor

Vulnerabilities

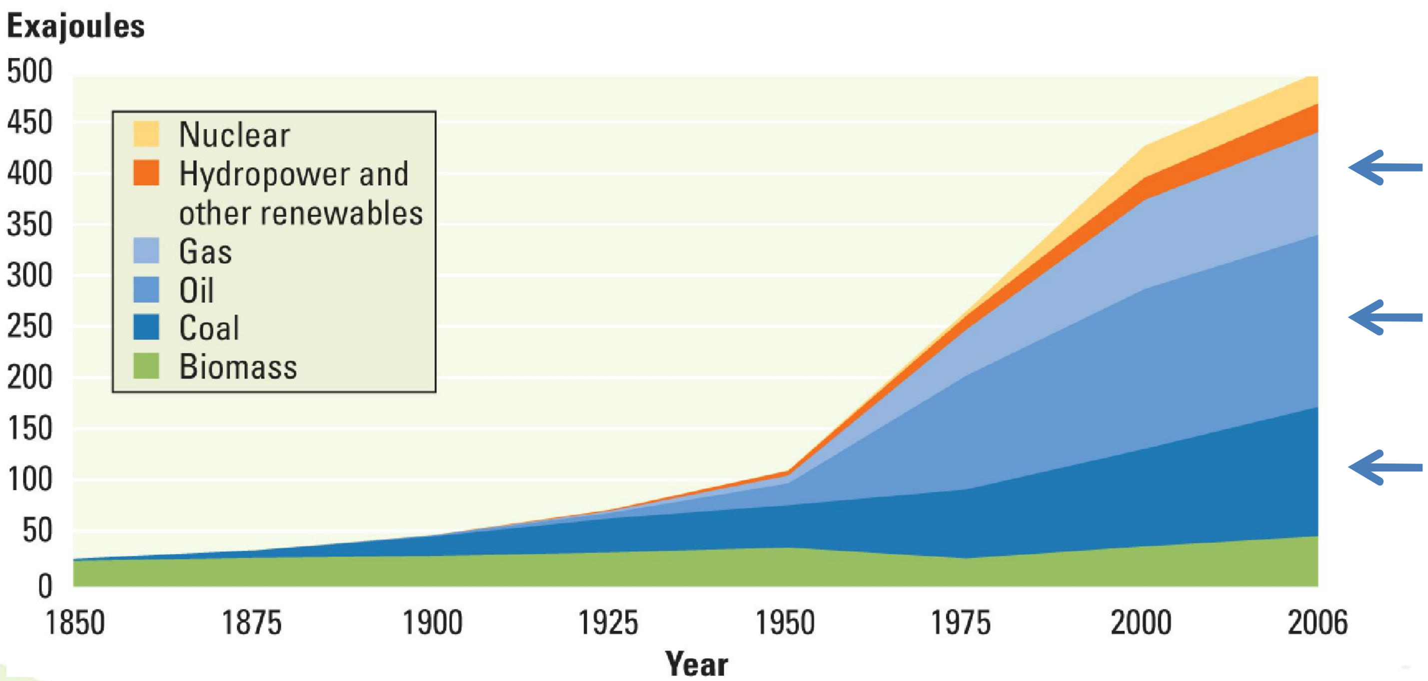
Growth rates of yields for major cereals are slowing in developing countries



Source: FAO 2006a.
Note: Data smoothed by locally weighted regressions.

Vulnerabilities

Modern agriculture is too dependent of non-renewable sources of energy



Primary energy mix 1850–2006. From 1850 to 1950 energy consumption grew 1.5 percent a year, driven mainly by coal. From 1950 to 2006 it grew 2.7 percent a year, driven mainly by oil and natural gas

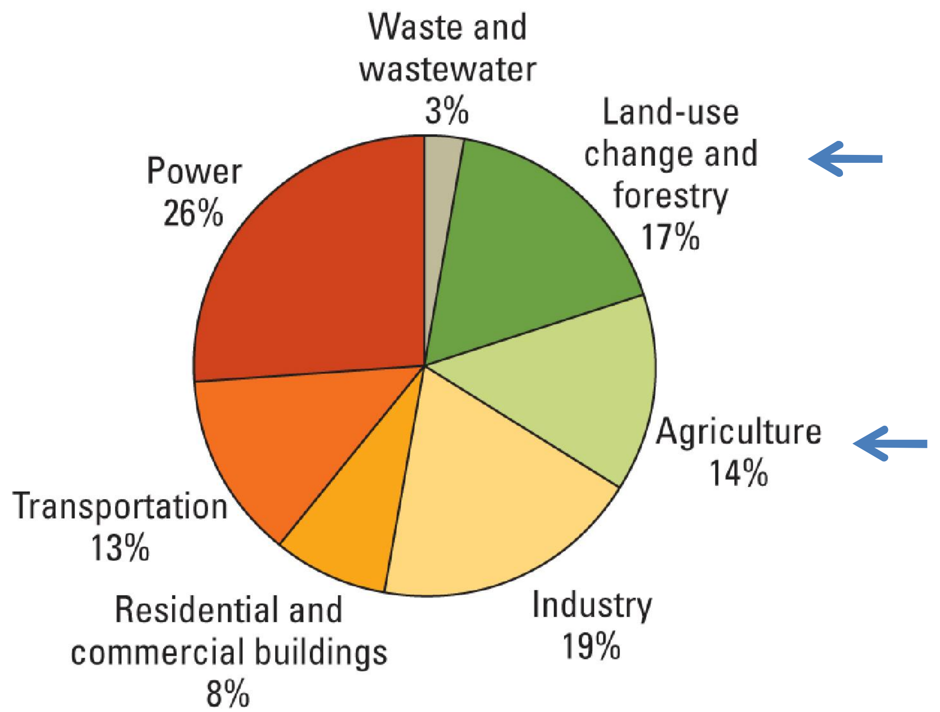
Source: WDR team, based on data from Grübler 2008 (data for 1850–2000) and IEA 2008c (data in 2006).

Note: To ensure consistency of the two data sets, the substitution equivalent method is used to convert hydropower to primary energy equivalent—assuming the amount of energy to generate an equal amount of electricity in conventional thermal power plants with an average generating efficiency of 38.6 percent.

Source: World Development Report 2010

Vulnerabilities

Global CO_2 emissions by sector: Energy, but also agriculture and forestry, are major sources



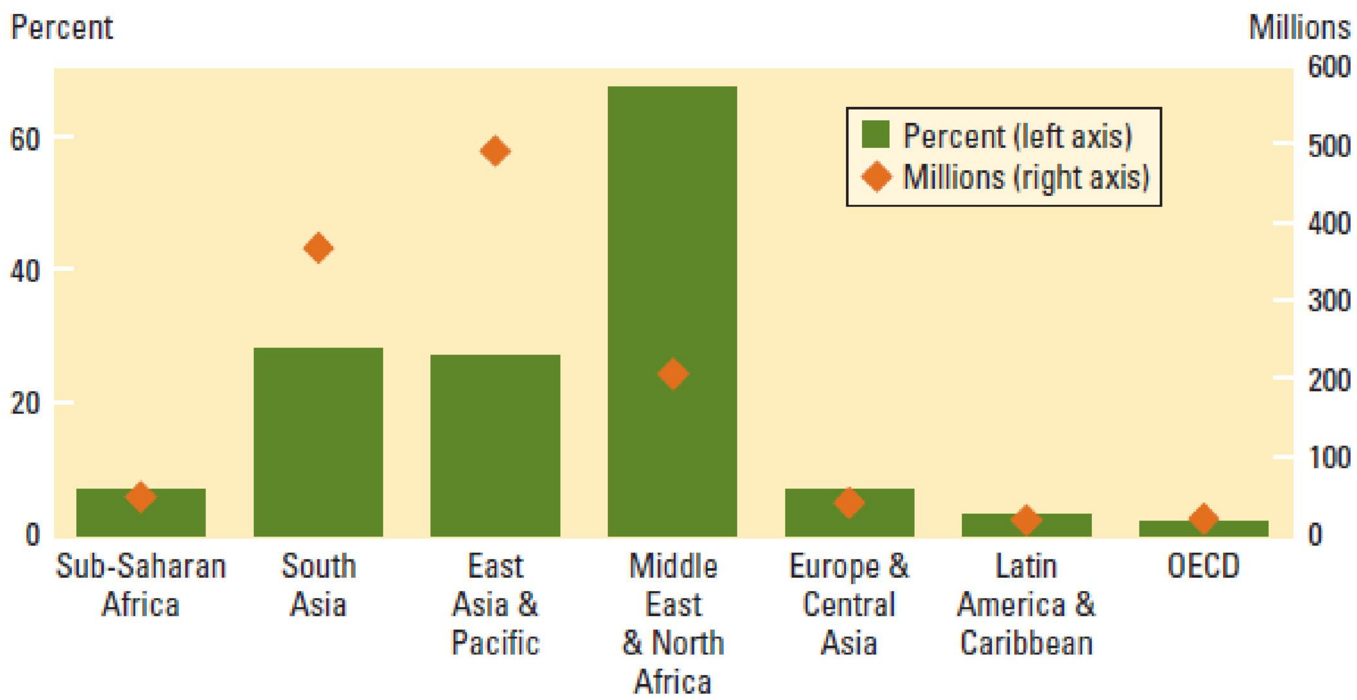
Source: IPCC 2007a, figure 2.1.

Note: Share of anthropogenic (human-caused) greenhouse gas emissions in 2004 in CO_2e (see figure 1 for the definition of CO_2e). Emissions associated with land use and land-use change, such as agricultural fertilizers, livestock, deforestation, and burning, account for about 30 percent of total greenhouse gas emissions. And uptakes of carbon into forests and other vegetation and soils constitute an important carbon sink, so improved land-use management is essential in efforts to reduce greenhouse gases in the atmosphere.

World Development Report 2010

Vulnerabilities

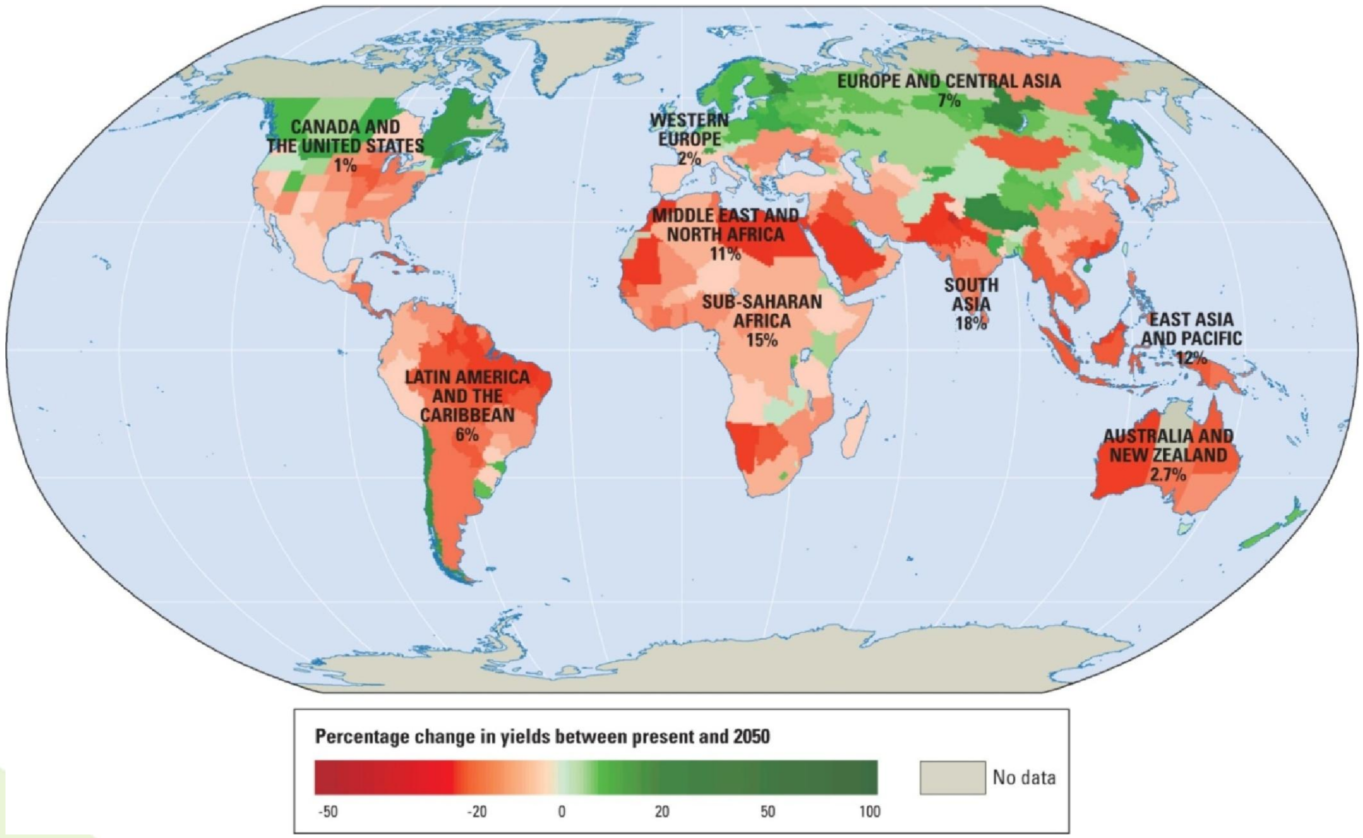
Population living in areas of absolute water scarcity



Source: International Water Management Institute (IWMI) analysis done for the Comprehensive Assessment of Water Management in Agriculture (2007) using the Watersim model.

Vulnerabilities

Climate change will depress agricultural yields in most countries in 2050, given current agricultural practices and crop varieties

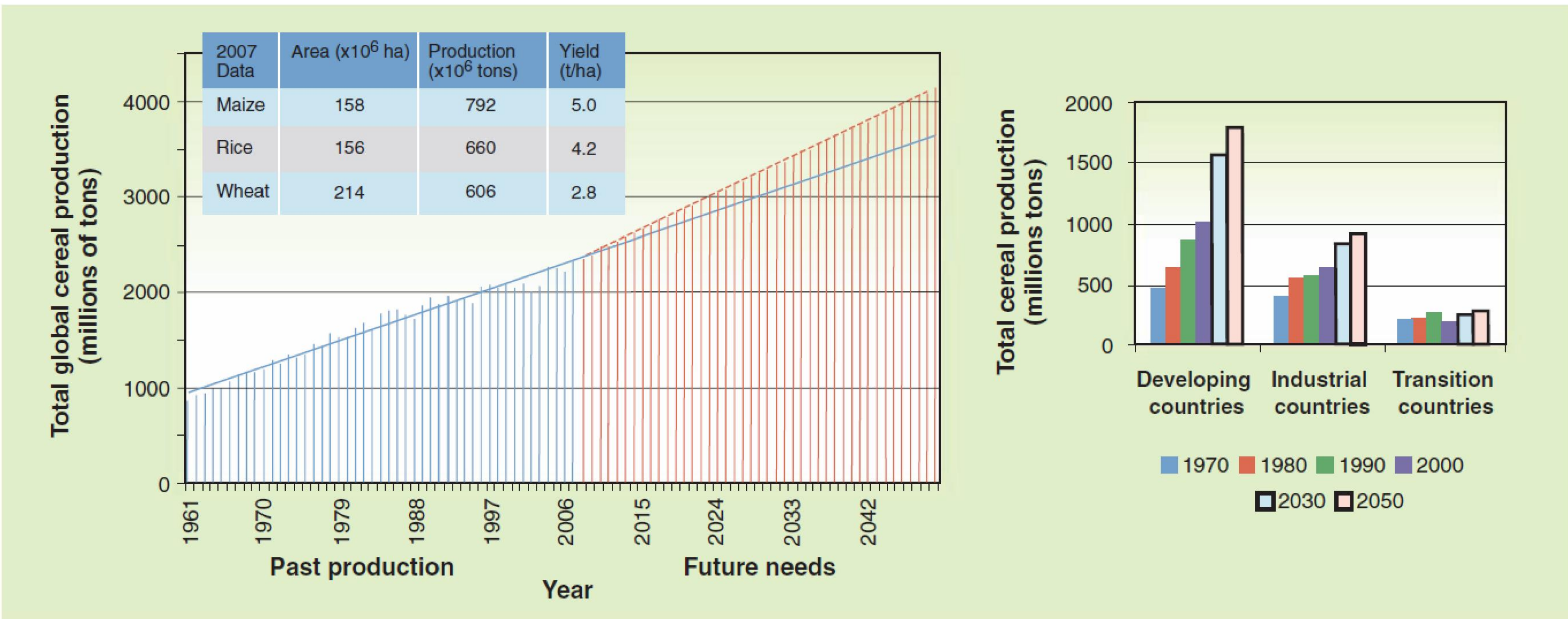


Note: The coloring in the figure shows the projected percentage change in yields of 11 major crops (wheat, rice, maize, millet, field pea, sugar beet, sweet potato, soybean, groundnut, sunflower, and rapeseed) from 2046 to 2055, compared with 1996–2005. The yield-change values are the mean of three emission scenarios across five global climate models, assuming no CO2 fertilization (a possible boost to plant growth and water-use efficiency from higher ambient CO2 concentrations). The numbers indicate the share of GDP derived from agriculture in each region. (**The share for Sub-Saharan Africa is 23 percent if South Africa is excluded**.) Large negative yield impacts are projected in many areas that are highly dependent on agriculture.

Source: World Development Report 2010

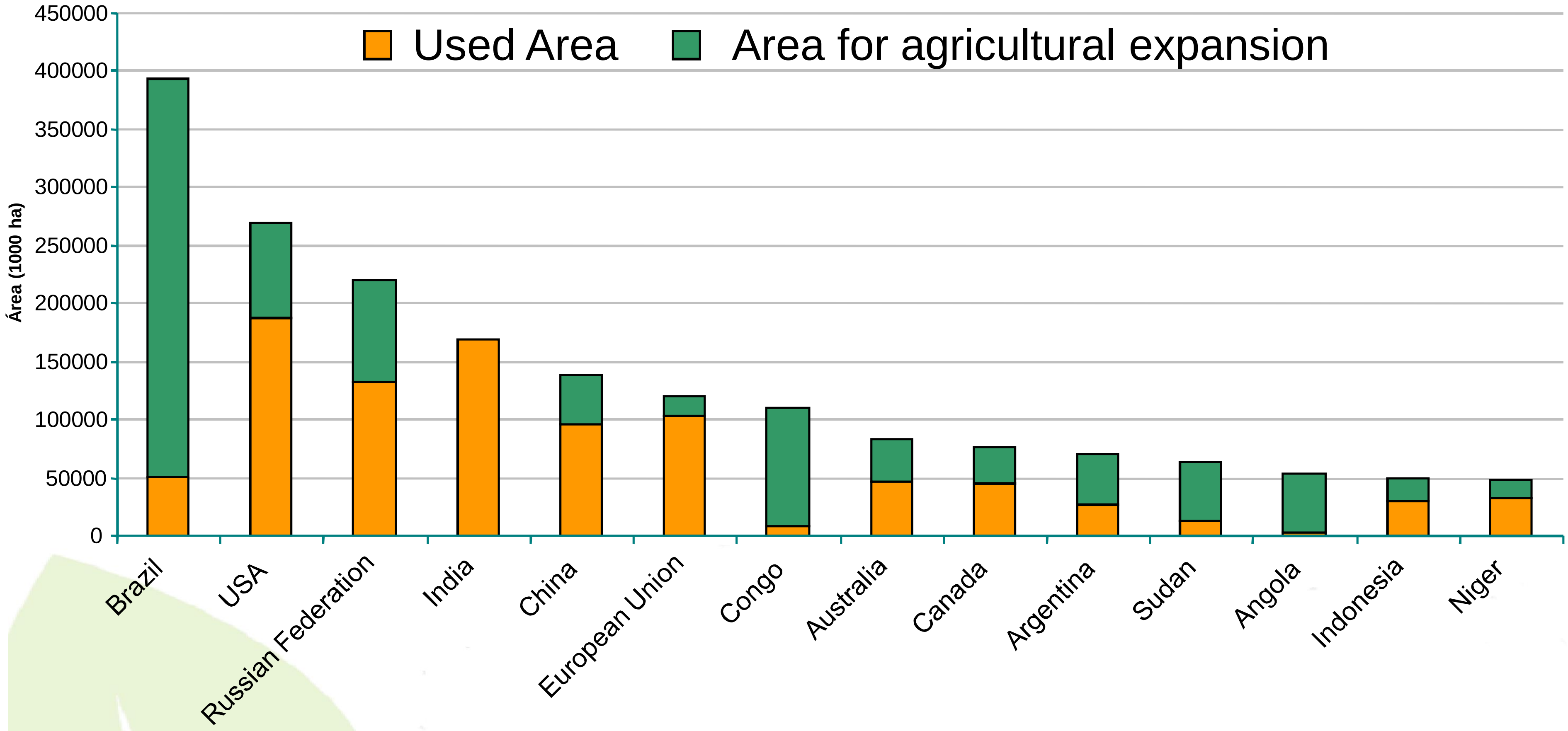
Vulnerabilities

"Cereal production targets"



Source: Tester and Langridge, Science Vol. 327. no. 5967, pp. 818 - 822

Vulnerabilities



Source: FAO

Vulnerabilities

A "Catch 22" for agriculture…

More people require more food

Requiring more intensive agriculture

Requiring more energy to produce food

Requiring use of more natural resources

Leading to more environmental degradation

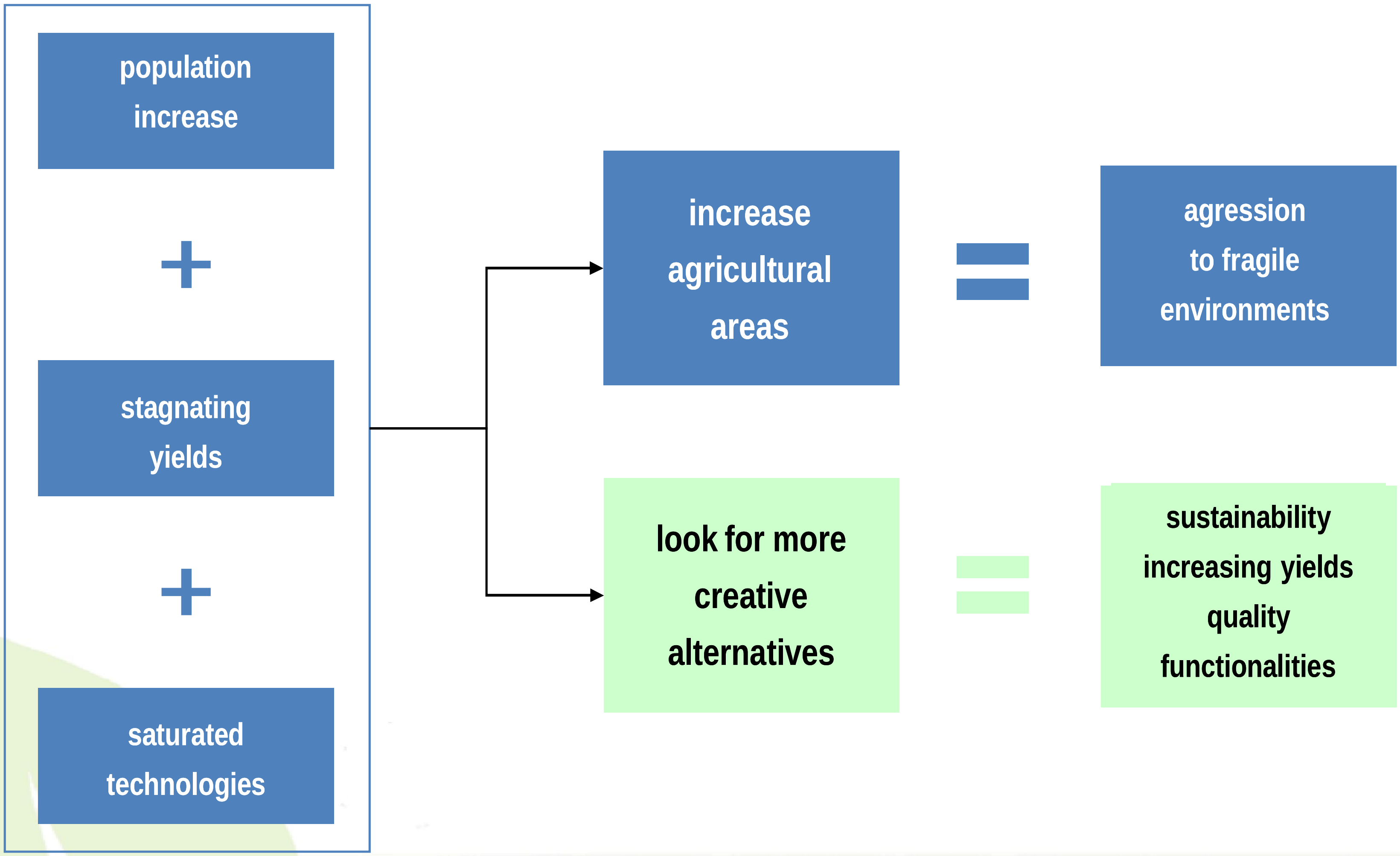
Leading to crop failure

Leading to starvation

Leading to migration to new lands

Requiring more people to produce food

Summary


population increase
+
stagnating yields
+
saturated technologies
increase agricultural areas
=
agression to fragile environments
look for more creative alternatives
=
sustainability
increasing yields
quality
functionalities

Sustainability of Modern Agriculture...

'The ability to meet the needs of the present without compromising the ability of future generations to meet their own needs'.

Source: World Commission on Environment and Development, 1987

Bottom line…

No single technology will do the trick…

Bottom line…

A mix of technologies and strategies needed…

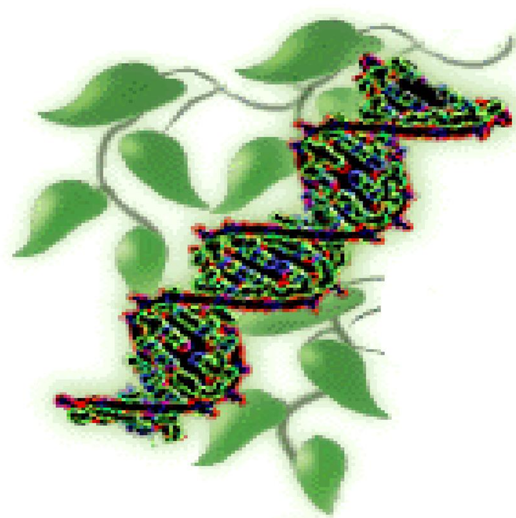
Modern Biotechnology is an important alternative…

Agricultural Biotechnology

Agriculture and the Emerging Bioeconomy ("Global Green Growth")

Food

Chemical



Fiber

Pharma

Energy

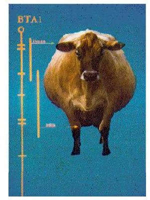
Biomaterials

Agricultural Biotechnology

GENETIC ENGINEERING

TRANSGENIC TECHNOLOGY

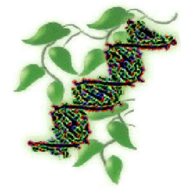
Biotic Stress Tolerance
Abiotic Stress Tolerance
Quality/Functionality
New Bioproducts



MOLECULAR MARKERS

MOLECULAR MAPS

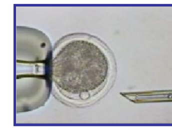
Gene/Trait Mapping
Genetic Resources Charc.
Function Characterization
Molecular Breeding



GENOMIC SCIENCES

GENOMICS
PROTEOMICS

Coffee
Eucalyptus
Banana/Rice
Bovine & Others



ADV. ANIMAL PRODUCTION

CLONING
IN-VITRO FERTILIZATION

Animal Breeding
GR Conservation
Germplasm Enhancement
Biofactories

GENETICS, PHYSIOLOGY, TISSUE CULTURE, BIOINFORMATICS, BIOSAFETY, ETC...

Agricultural Biotechnology

GENETIC ENGINEERING

TRANSGENIC TECHNOLOGY

Biotic Stress Tolerance
Abiotic Stress Tolerance
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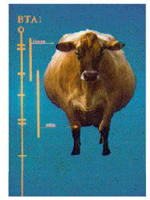

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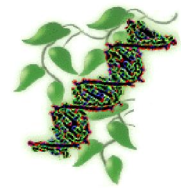

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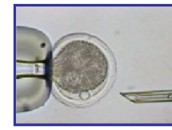


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The Timeline of Biotechnology

1859 - Charles Darwin publishes “The Origin of Species”, establishing the Theory of Evolution and its mechanism, natural selection...

1865 - The age of genetics begins when Gregor Mendel, studying inherited traits of pea plants. Outlines the basic laws of heredity that still hold true today for all organisms...

1910 - Thomas Hunt Morgan proposes the chromosomal theory of inheritance. Establishes that genes are located on chromosomes…

1941 - One gene, one enzyme: George Beadle and Edward Tatum establish that one gene makes one enzyme or protein...

1952 - Martha Chase and Alfred Hershey demonstrate that DNA is the substance that transmits inherited characteristics from one generation to the next...

The Timeline of Biotechnology

1953 - James Watson and Francis Crick deduce the structure of the DNA molecule - a double helix...

1967 – Genetic code cracked. Har Khorana, Robert Holley and Marshall Nirenberg decipher the mechanism that enables DNA to be translated into proteins...

1968 - Stanley Cohen determines that bacteria carry genes for antibiotic resistance on plasmids, extrachromosomal circles of DNA...

1970 - Restriction enzymes discovered. In the ensuing years, hundreds of different restriction endonucleases are found that cleave DNA at specific sites...

1972 - Recombinant DNA technology begins. Stanford biochemist Paul Berg splices together two blunt-ended fragments of DNA from the SV40 virus and E. coli, creating recombinant DNA...

The Timeline of Biotechnology

1972 - Sticky ends of "restricted" DNA can be linked together or "spliced" with DNA ligases. Insertion of desired DNA into bacterial plasmids - the basis of the biotechnology industry...

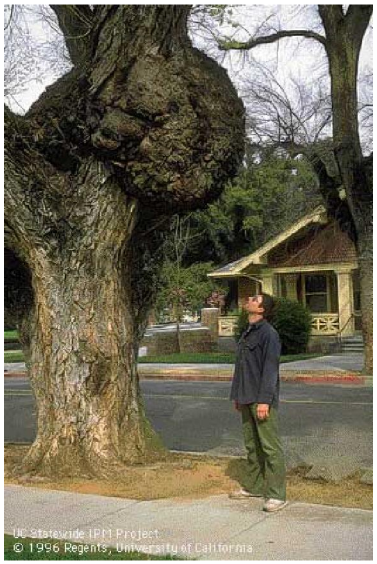
1975 - Asilomar Conference held in Pacific Grove CA. A conference on recombinant DNA technology with over 100 other scientists to discuss what they knew (and didn't know) about recombinant DNA and to draw up guidelines that would let the science proceed without undue risk. The scientists agree to suspend research involving recombinant DNA technology research until potential risks could be evaluated.

1975 - DNA sequencing developed. Walter Gilbert and Allan Maxam of Harvard University and Fred Sanger of Cambridge University simultaneously come up with two techniques for determining the exact sequence of bases that make up a gene.

1980 - The Birth of Plant Biotech…

Genetic Engineering

Learning with nature….

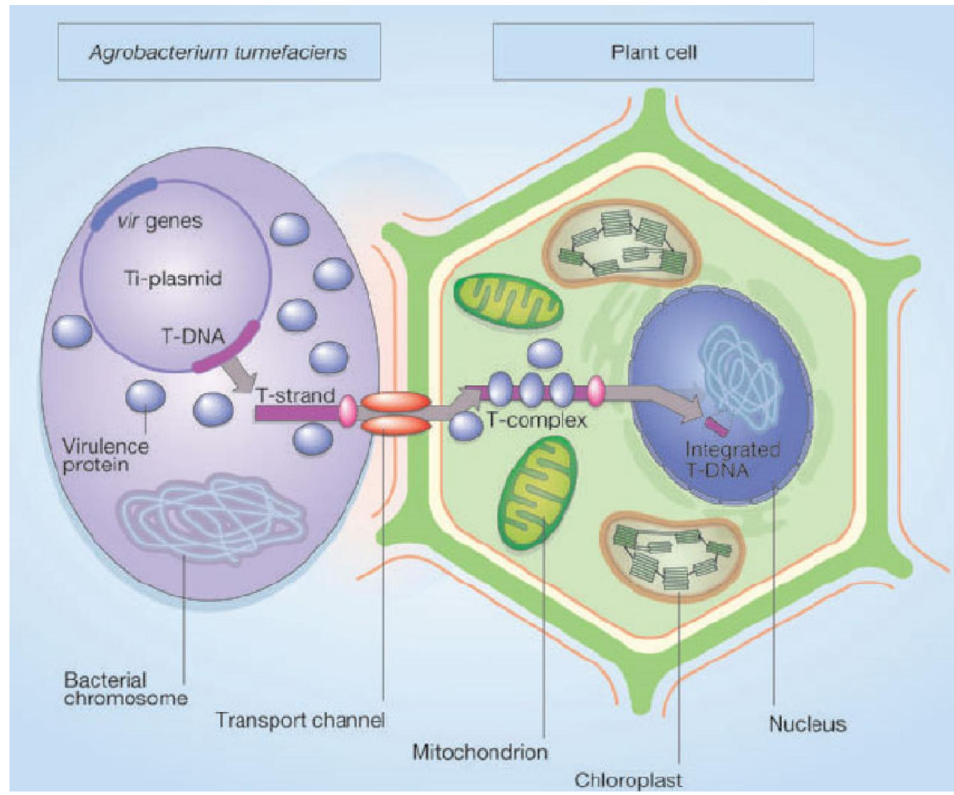


http://www.ag.ndsu.edu/pubs/plantsci/crops/a1219-3.jpg

http://www.bio.uio.no/plfys/haa/gen/gmo.htm

Agrobacterium tumefaciens is the causal agent of crown gall disease (that lead to formation of tumors) in plants.

Symptoms are caused by the insertion of a small segment of DNA (known as the T-DNA, for 'transfer DNA') into the plant cell, which is incorporated at a semi-random location into the plant genome.



Source: http://www.biotecheambiente.com/

Genetic Engineering

1980: First transgenic plants.

Several research groups used *Agrobacterium tumefaciens* to insert a Ti plasmid DNA into tobacco. Showed that the bacterium could be used as a gene vector, creating tobacco plants that were kanamycin resistant.

Doors opened for plant genetic engineering

Find the genes for some specific traits

Place genes in organisms where they did not originate

Get those genes to work in their new location

Genetic Engineering

Basic Principles

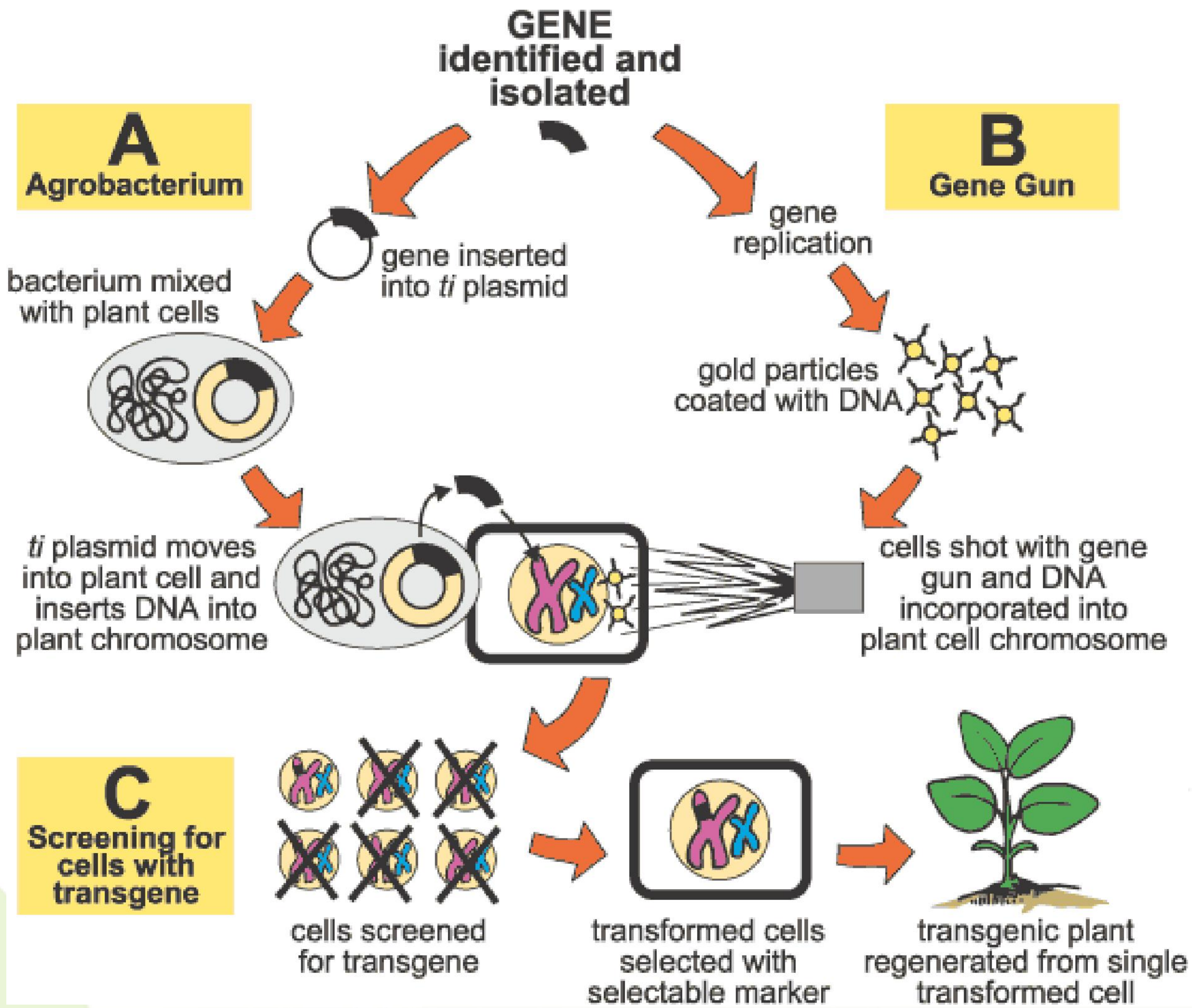
Genetic transformation requires a:

1) Vector or way to transfer the genetic material into the cell;

2) Means of screening for transformed cells;

3) Means of regenerating the organism from the individual cell that is transformed.

Genetic Engineering



Source: A Basic Primer on Biotechnology , http://www.ag.ndsu.edu

Genetic Engineering – Traits Targeted

<u>Agronomic Traits</u> – (*input traits*)

- **Biotic Stress**
  - Insect Resistance
  - Disease Resistance - Viral, Bacterial, Fungal, Nematode
  - Weed- herbicide tolerance
- **Abiotic Stress**
  - Drought, Cold, Heat, Poor soils
- **Yield**
  - Nitrogen Assimilation, Starch Biosynthesis, O2 Assimilation

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<u>Quality Traits</u> (*output traits*)

- Processing
- Shelf-life
- Reproduction: sex barriers, male sterility, seedlessness
- Nutrients (Nutraceuticals)
  - Macro: Protein, Carbohydrates, Fats
  - Micro: vitamins, antioxidants, minerals, isoflavonoids, glucosinolates, phytoestrogens, lignins, condensed tannins
  - Anti-nutritionals: Phytase, Toxin removal
- Taste
- Architecture
- Fiber
- Ornamentals: color, shelf-life, morphology, fragrance

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Novel Crop Products

- Oils
- Proteins: nutraceuticals, therapeutics, vaccines
- Polymers

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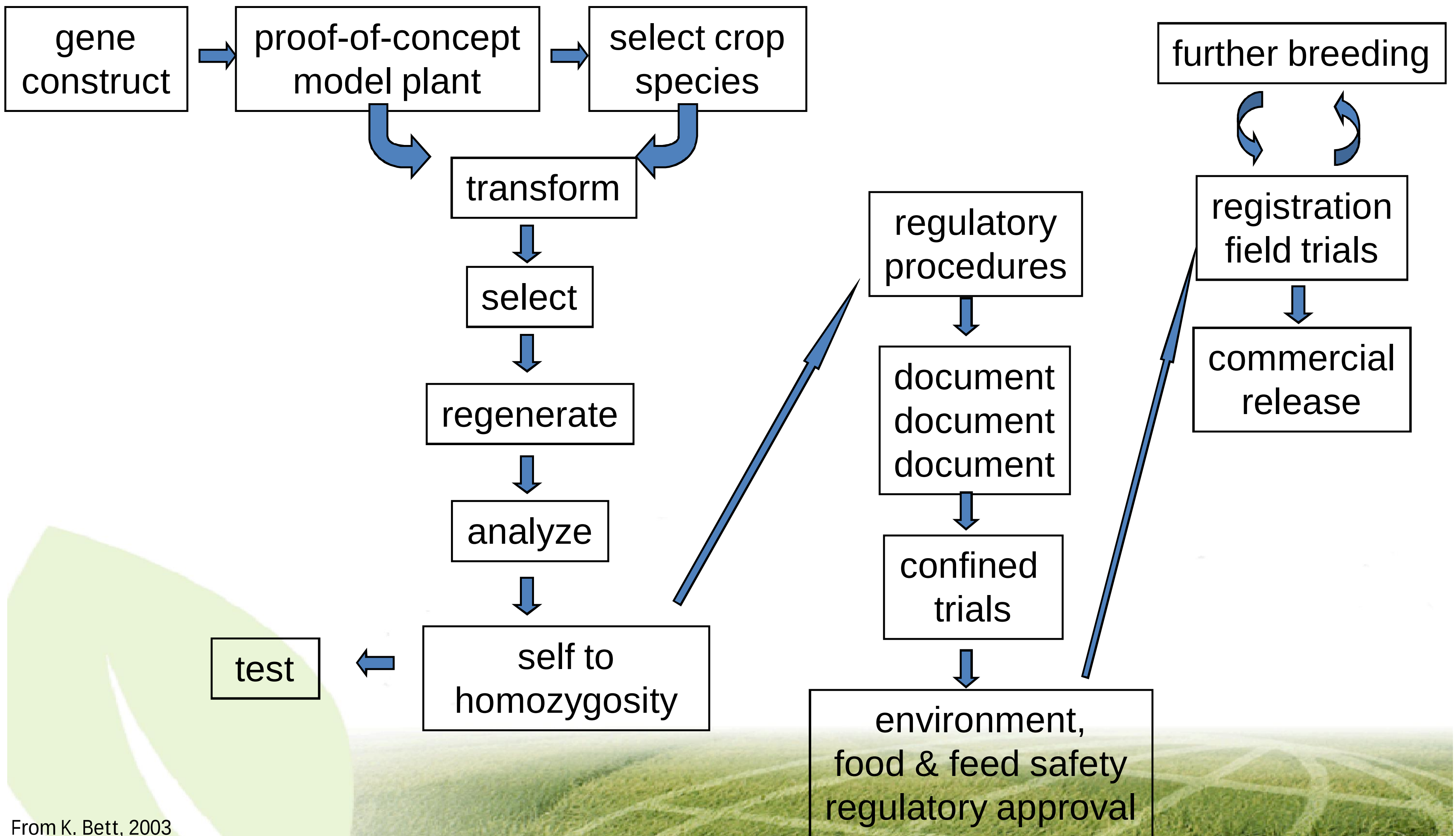
<u>Novel Crop Products</u>

- Oils
- Proteins: nutraceuticals, therapeutics, vaccines
- Polymers

<u>Renewable resources</u>

- Biomass conversion, feedstocks, biofuels

Genetic Engineering
From Concept to Products



From K. Bett, 2003

Genetic Engineering
From Concept to Products

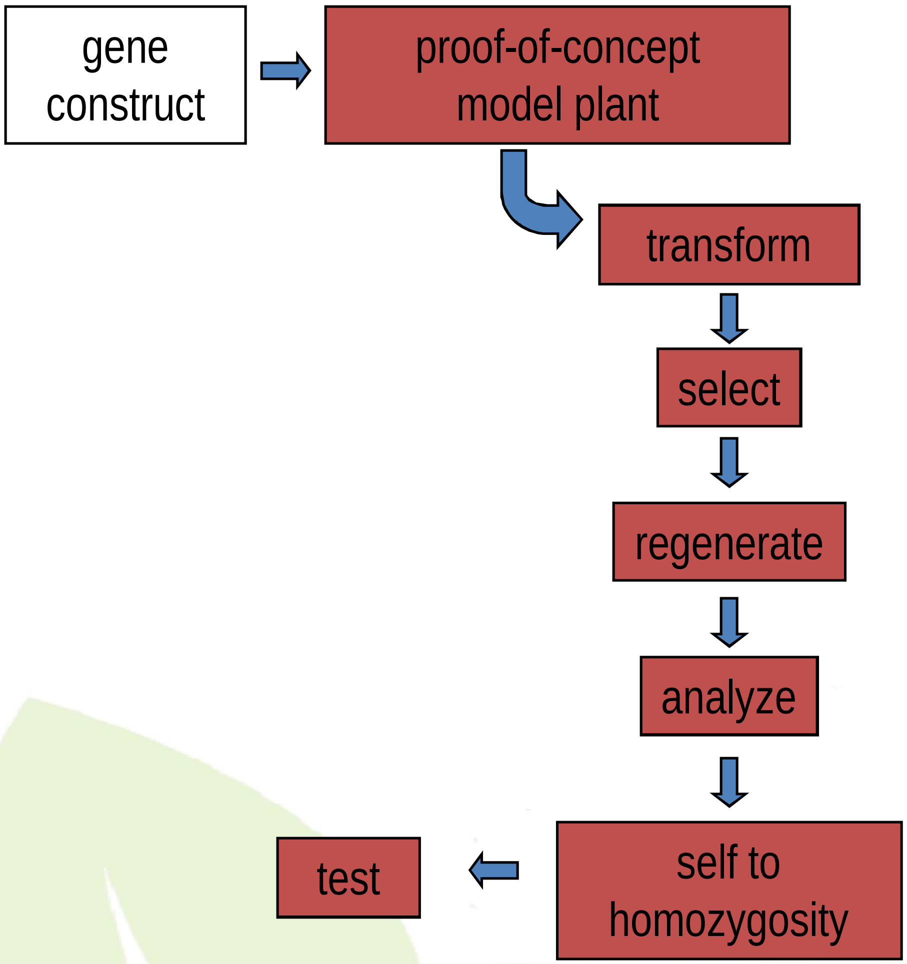
gene construct

- gene of interest
- promoter
    - constitutive
    - tissue-specific
    - temporal
- selectable marker
- enhancer elements

From K. Bett, 2003

Genetic Engineering

From Concept to Products



- Agrobacterium
- biolistics

- using selectable markers
  - antibiotic resistance
  - herbicide resistance

- copy number
- presence of gene activity
- phenotype

From K. Bett, 2003

Genetic Engineering
From Concept to Products

Regulatory Procedures

↓

document
document
document

↓

confined trials

↓

environment, food & feed safety regulatory approval

- scientific and common names
- description of life cycle and habitats
- where is it a known pest?
- tendency towards weediness & dormancy
- mechanism of pollen, seed and vegetative dispersal
- mechanism of out-crossing
- information of known toxins

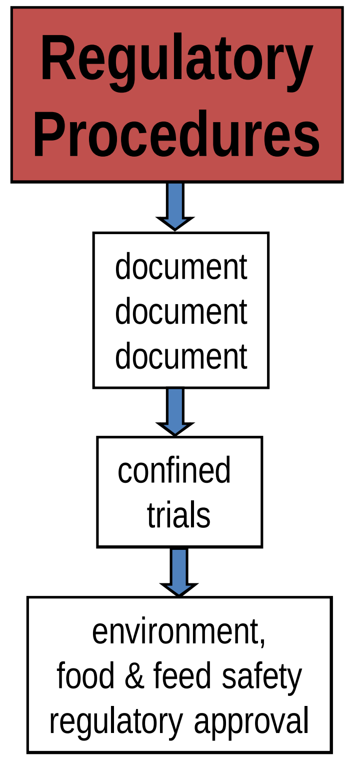
- map + description of biodiversity at site
- isolation distances; border/guard rows
- prevention of pollen movement
- info on pesticide use, harvest methodology, post-harvest use of land
- contingency plan in case of accidental release
- monitoring during and post trial

- description of trait and method of modification
- description of expression
  - tissue specificity
  - developmental stage
  - stability
- confirm no change to dormancy or weediness
- toxicity, allergenicity, nutritional studies
- fate of gene product when ingested

From K. Bett, 2003

Genetic Engineering
From Concept to Products

up to 90% of the cost of getting the product to market can occur at these regulatory steps



From K. Bett, 2003

Genetic Engineering
Herbicide Tolerant Crops

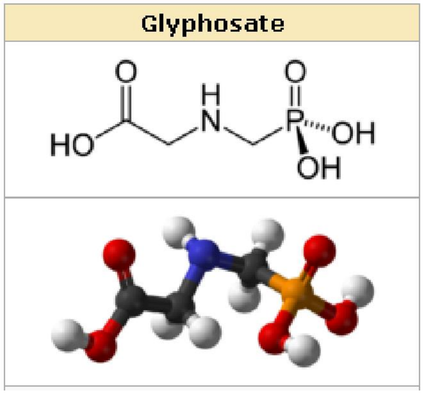
Herbicides target specific enzymes or processes

- Target is usually specific and key to plant metabolism.
- Engineering resistance involves modification of the target enzyme or introduction of an enzyme that detoxifies the herbicide.
- The modified or introduced enzyme can usually be obtained from bacteria, fungi, or other plants.

Genetic Engineering
Herbicide Tolerant Crops

The Case of Roundup Ready™

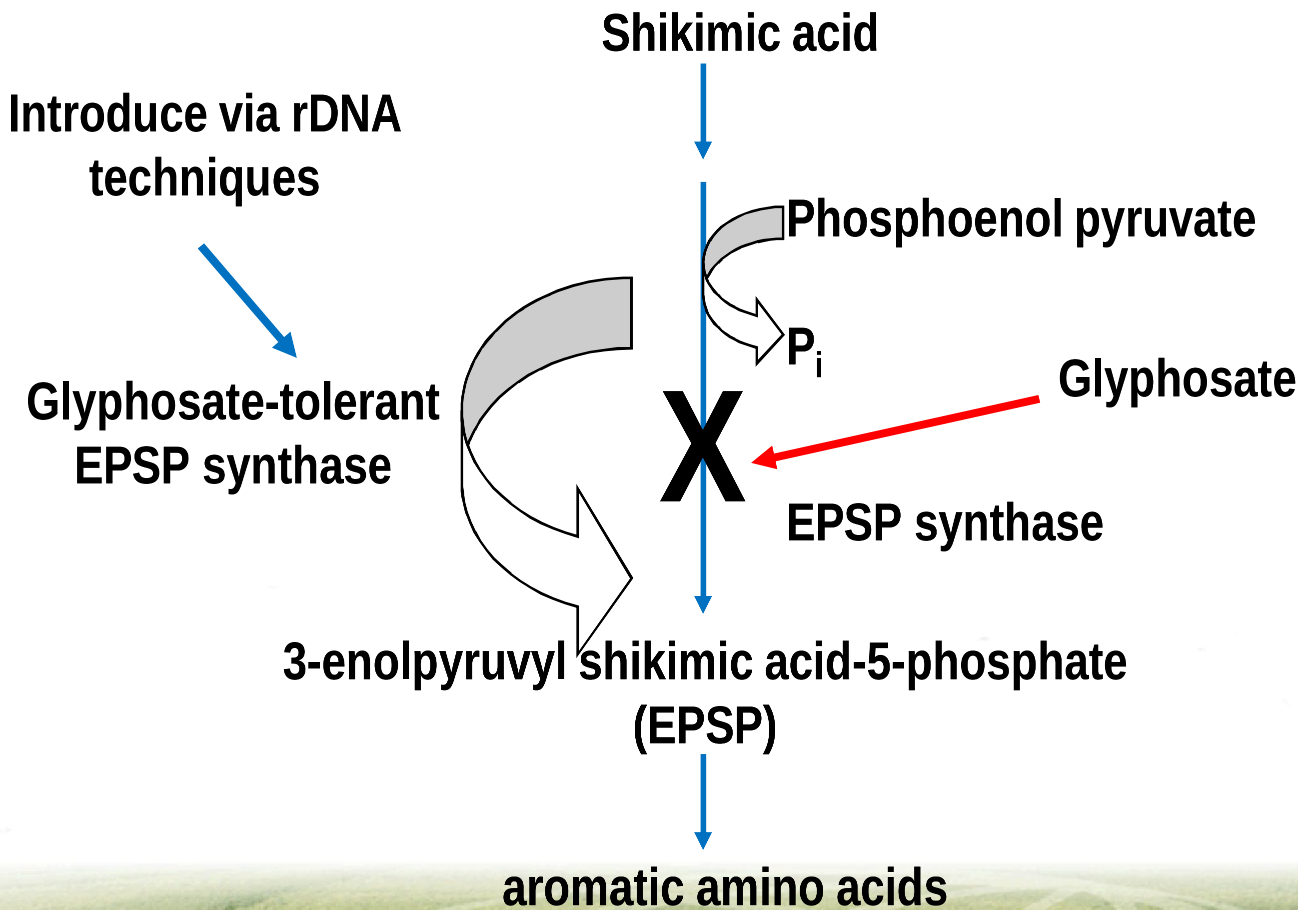
Genetic engineered crops resistant to the molecule Glyphosate (N-(phosphonomethyl) glycine), that is a broad-spectrum systemic herbicide used to kill weeds. It is typically sprayed and absorbed through the leaves. Initially patented by Monsanto Company in the 1970s under the tradename Roundup, its U.S. patent expired in 2000.



http://www.answers.com/topic/glyphosate

Genetic Engineering
Herbicide Tolerant Crops

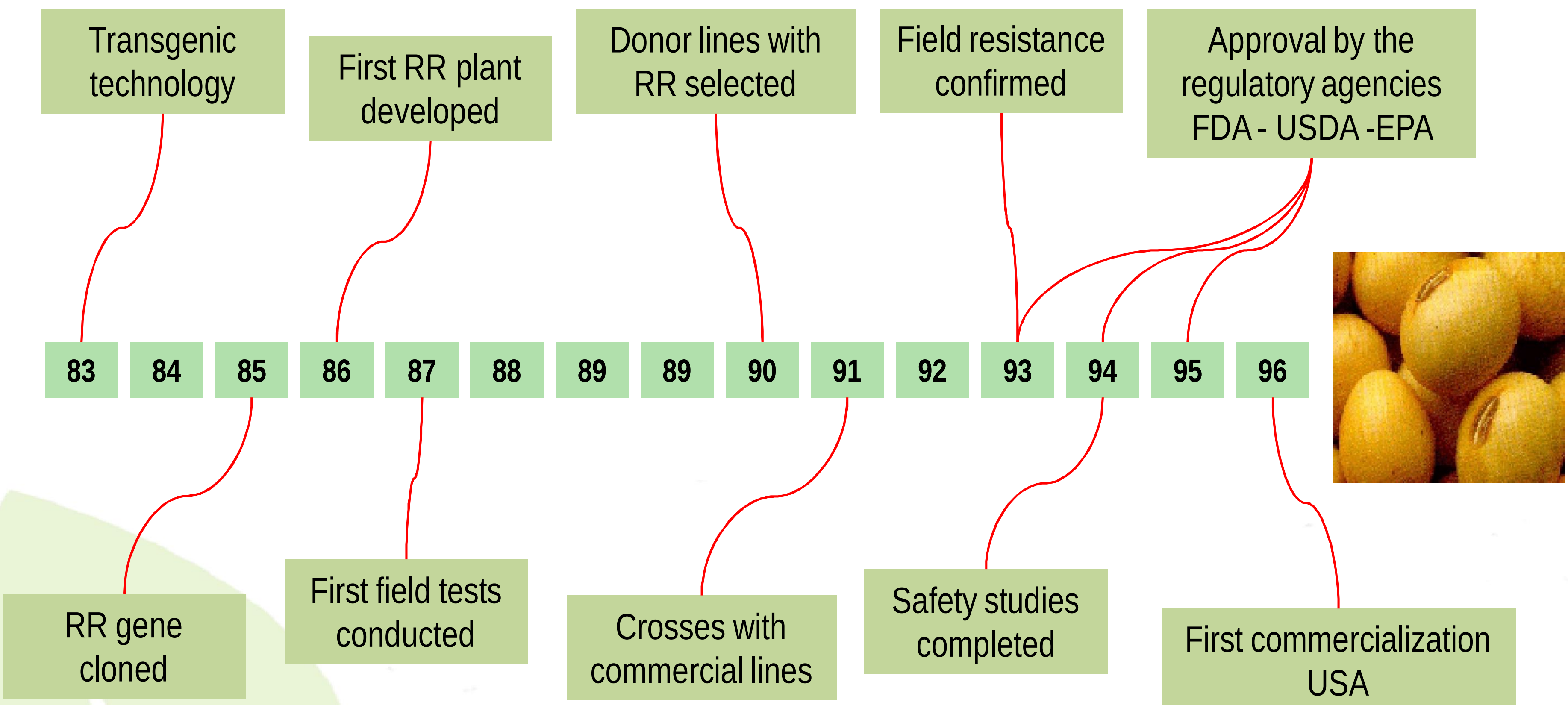
The Case of Roundup Ready™



Genetic Engineering

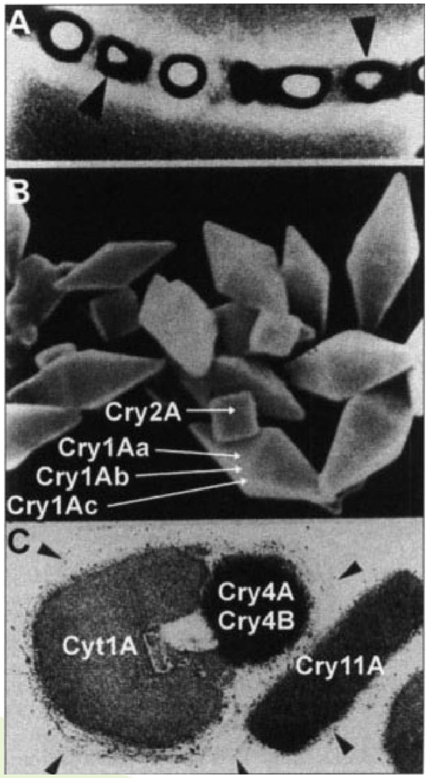
Herbicide Tolerant Crops

The Case of Roundup Ready™



Genetic Engineering

Insect-Resistant Crops – Bt Technology



Sporulated culture and parasporal bodies of *Bacillus thuringiensis* *(Bt)*.

Identify specific Bt strain active on target pest.

↓

Isolate DNA coding for *cry* protein from bacteria.

↓

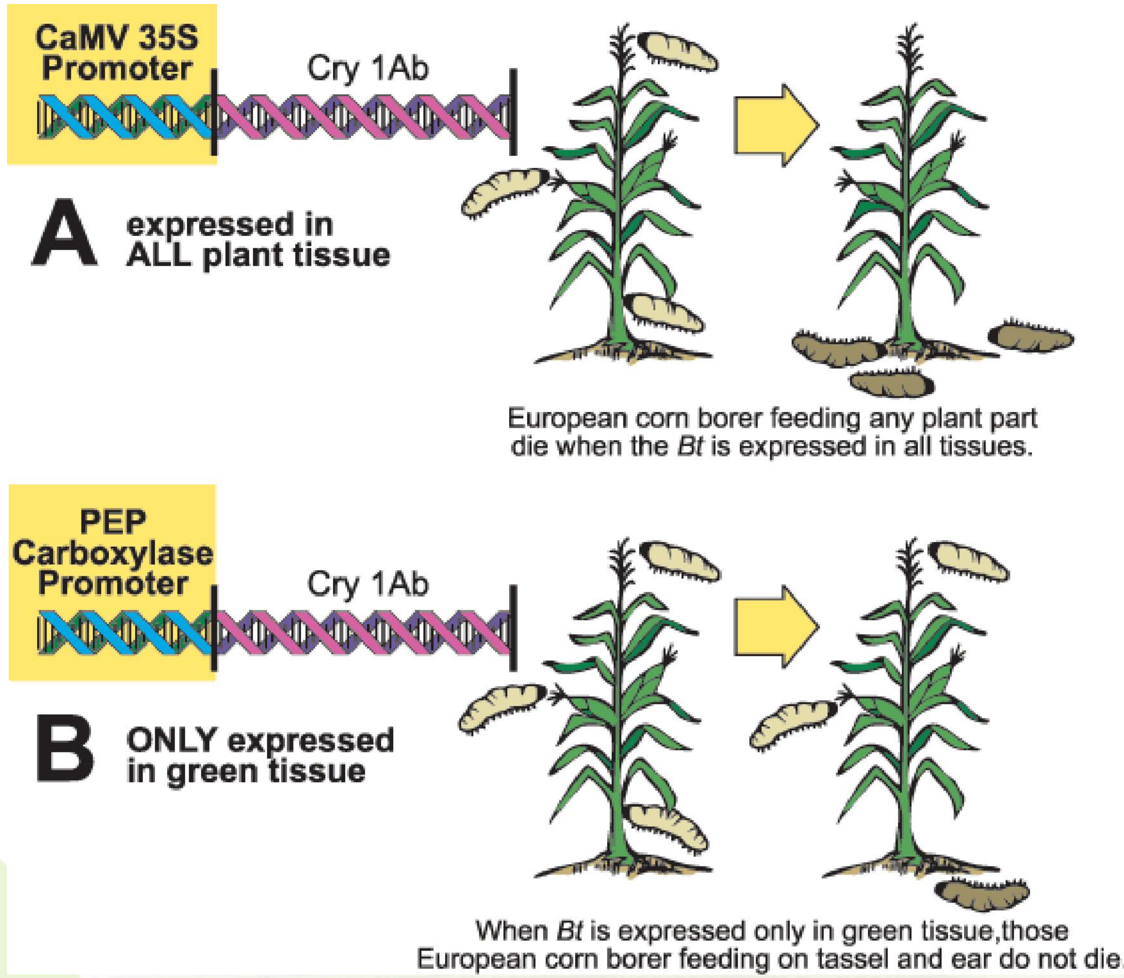
Introduce DNA coding for *cry* protein into crop plant.

↓

Test for expression, stability, effectiveness and safety.

Source: B.A. Federici, UC Riverside, USA. http://tinyurl.com/25uj2qc

Genetic Engineering
Insect-Resistant Crops



Source: A Basic Primer on Biotechnology , http://www.ag.ndsu.edu

Genetic Engineering

Insect-Resistant Crops

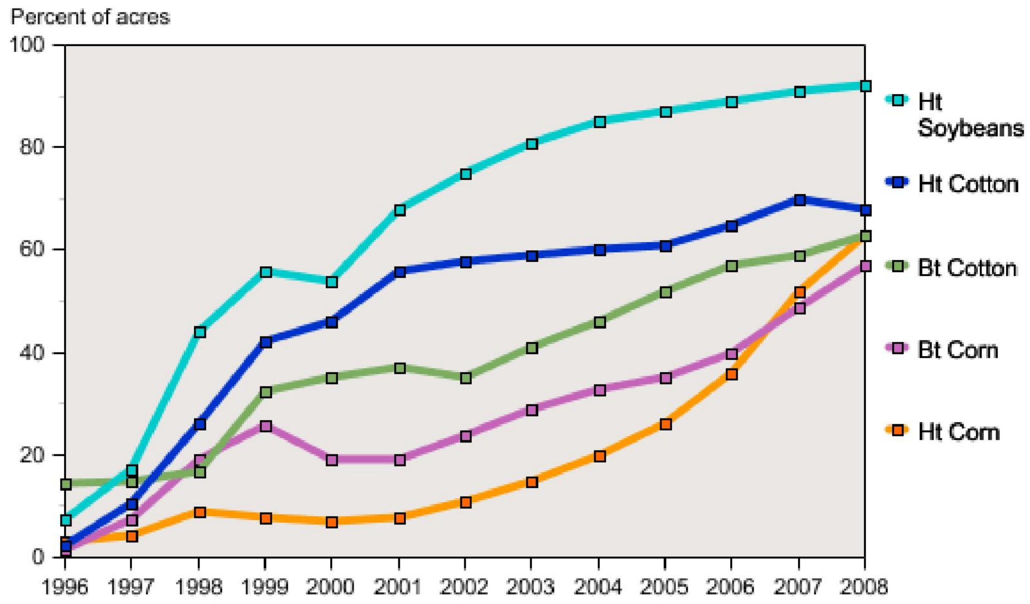
Reduce applications of insecticides to control pests.

Reduce occurrence of secondary toxins (e.g., reduced fumonisin in Bt corn).

Preserve beneficial insects.

Adoption of GM Technology

Adoption of Genetically Modified Crops in the U.S.



Source: Adoption of Genetically Engineered Crops in the U.S., data obtained by USDA's National Agricultural Statistics Service (NASS) in the June Agricultural Survey for 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, and 2008.

Adoption of GM Technology

Country Areas Cultivated with GM Crops in 2008

Rank	Country	Area (million hectares)	Biotech Crops
1*	USA*	62.5	Soybean, maize, cotton, canola, squash, papaya, alfalfa, sugarbeet
2*	Argentina*	21.0	Soybean, maize, cotton
3*	Brazil*	15.8	Soybean, maize, cotton
4*	India*	7.6	Cotton
5*	Canada*	7.6	Canola, maize, soybean, sugarbeet
6*	China*	3.8	Cotton, tomato, poplar, petunia, papaya, sweet pepper
7*	Paraguay*	2.7	Soybean
8*	South Africa*	1.8	Maize, soybean, cotton
9*	Uruguay*	0.7	Soybean, maize
10*	Bolivia*	0.6	Soybean
11*	Philippines*	0.4	Maize
12*	Australia*	0.2	Cotton, canola, carnation
13*	Mexico *	0.1	Cotton, soybean
14*	Spain *	0.1	Maize
15	Chile	<0.1	Maize, soybean, canola
16	Colombia	<0.1	Cotton, carnation
17	Honduras	<0.1	Maize
18	Burkina Faso	<0.1	Cotton
19	Czech Republic	<0.1	Maize
20	Romania	<0.1	Maize
21	Portugal	<0.1	Maize
22	Germany	<0.1	Maize
23	Poland	<0.1	Maize
24	Slovakia	<0.1	Maize
25	Egypt	<0.1	Maize

* 14 biotech mega-countries growing 50,000 hectares, or more, of biotech crops
Source: Clive James, 2008.

Adoption of GM Technology

Major Biotech Crops

Soybean

- 70% (65.8 million has.) of total global soybean planted is biotech
- US$4B increase in farmer income in 2007
- Countries growing biotech soybean: *Argentina, Bolivia, Brazil, Canada, Chile, Mexico, Paraguay, Uruguay, South Africa, and the USA.*

Cotton

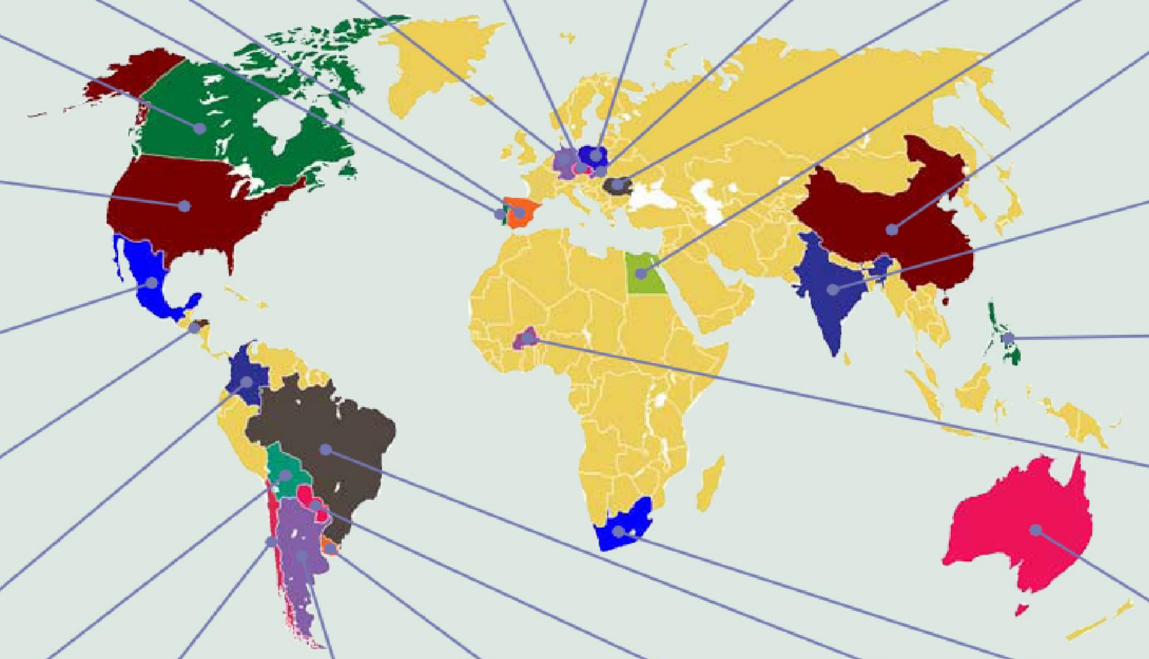
- 46% (15.5 million has.) of total global cotton planted is biotech
- US$3.3B increase in farmer income in 2007
- Countries growing biotech cotton: *Argentina, Australia, Brazil, Burkina Faso, China, Colombia, India, Mexico, South Africa, and the USA.*

Maize

- 24% (37.3 million has.) of total global maize planted is biotech
- US$2.4B increase in farmer income in 2007
- Countries growing biotech maize: *Argentina, Brazil, Canada, Chile, Czech Republic, Egypt, Germany, Honduras, Philippines, Poland, Portugal, Romania, Slovakia, South Africa, Spain, Uruguay, and the USA.*

Canola

- 20% (5.9 million has.) of total global canola planted is biotech
- US$0.4B increase in farmer income in 2007
- Countries growing biotech canola: *Canada, Chile, and the USA.*



#21 *Portugal*
<0.05 Million Has.
Maize

#14 *Spain**
0.1 Million Has.
Maize

#22 *Germany*
<0.05 Million Has.
Maize

#19 *Czech Republic*
<0.05 Million Has.
Maize

#23 *Poland*
<0.05 Million Has.
Maize

#24 *Slovakia*
<0.05 Million Has.
Maize

#20 *Romania*
<0.05 Million Has.
Maize

#25 *Egypt*
<0.05 Million Has.
Maize

#5 *Canada**
7.6 Million Has.
Canola, Maize, Soybean Sugar beet

#1 *USA**
62.5 Million Hectares
Soybean, Maize, Cotton, Canola, Squash, Papaya, Alfalfa, Sugar beet

#13 *Mexico**
0.1 Million Hectares
Cotton, Soybean

#17 *Honduras*
<0.05 Million Hectares
Maize

#16 *Colombia*
<0.05 Million Hectares
Cotton, Carnation

#6 *China**
3.8 Million Has.
Cotton, Tomato, Poplar, Petunia, Papaya, Sweet Pepper

#4 *India**
7.6 Million Has.
Cotton

#10 *Philippines**
0.4 Million Has.
Maize

#18 *Burkina Faso*
<0.05 Million Has.
Cotton

#11 *Australia**
0.2 Million Has.
Cotton, Canola, Carnation

#10 *Bolivia**
0.6 Million Hectares
Soybean

#15 *Chile*
<0.05 Million Hectares
Maize, Soybean, Canola

#2 *Argentina**
21.0 Million Hectares
Soybean, Maize, Cotton

#9 *Uruguay**
0.7 Million Hectares
Soybean, Maize

#7 *Paraguay**
2.7 Million Hectares
Soybean

#3 *Brazil**
15.8 Million Has.
Soybean, Maize, Cotton

#8 *South Africa**
1.8 Million Has.
Maize, Soybean, Cotton

* 14 biotech mega-countries growing 50,000 hectares, or more, of biotech crops.

For more information about ISAAA, contact the Center nearest you:

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ISAAA *Afri*Center
c/o CIP
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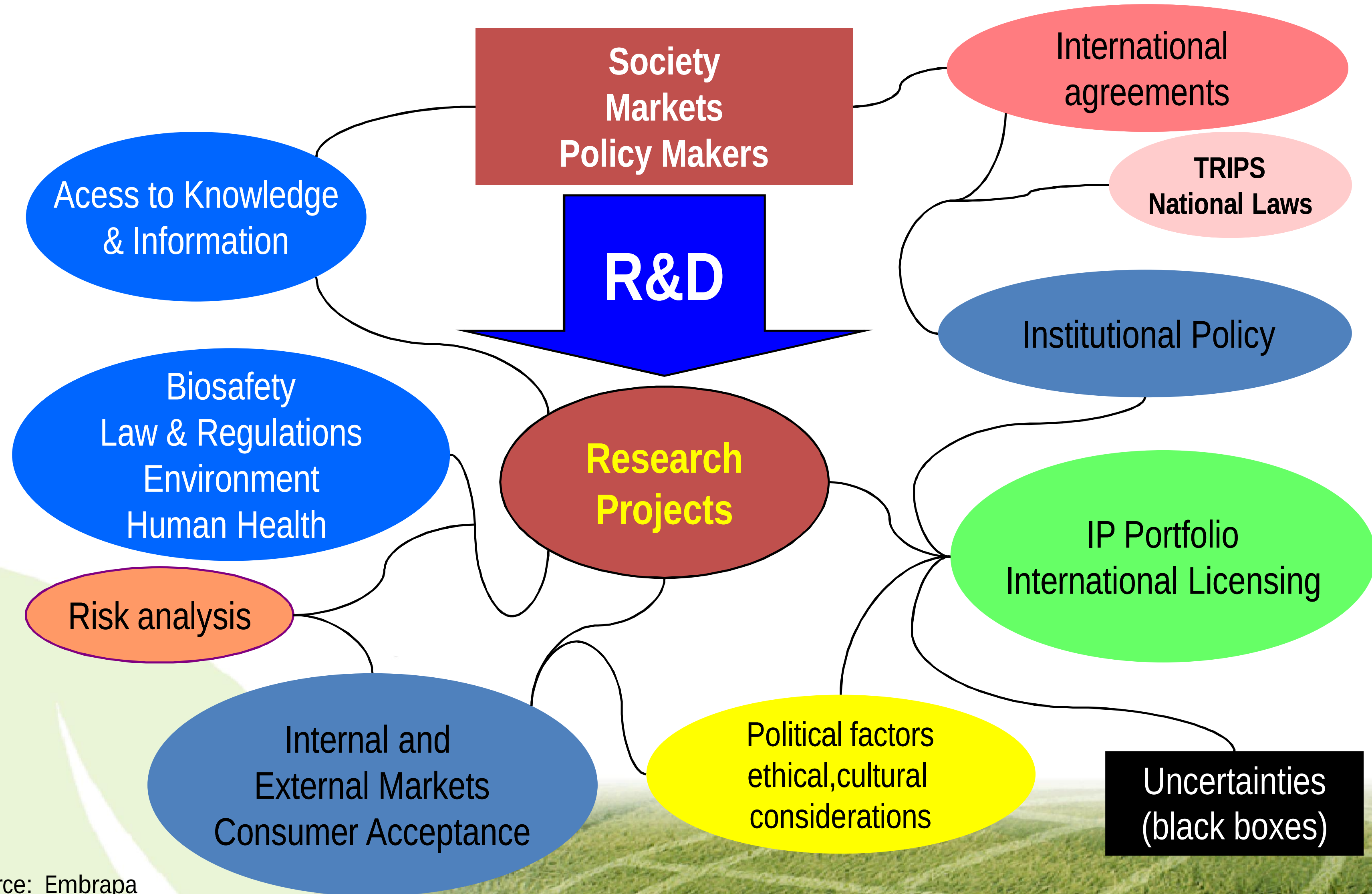
Email: africenter@isaaa.org

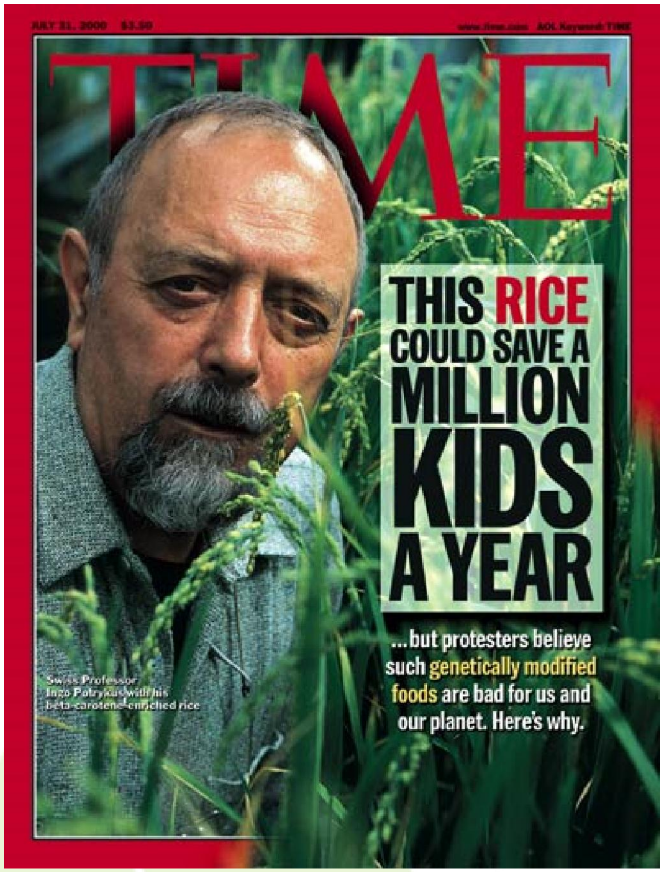
ISAAA *SEAsia*Center
c/o IRRI, DAPO Box 7777
Metro Manila, Philippines
Email: isaaa-seasia@isaaa.org

Complexities of GM Technology Development & Application
Society – Policy - Markets

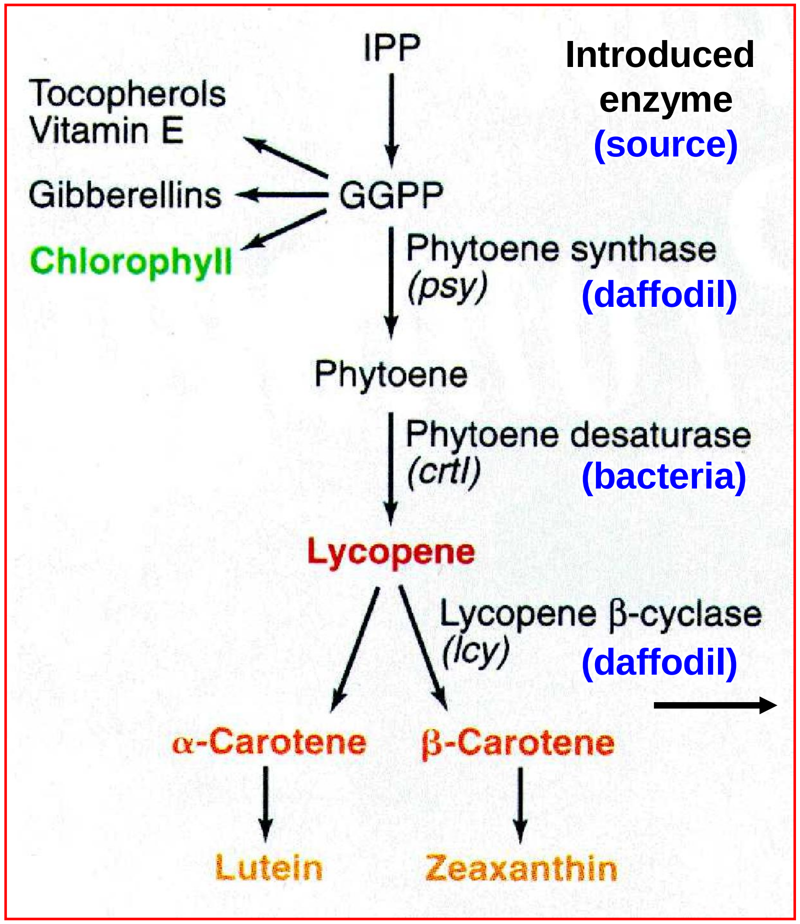


Source: Embrapa

Genetic Engineering
Output traits



http://www.time.com/time/



Ye et al. (2000) Science 287: 303-305.

"*Golden*Rice™"

Complexities of GM Technology Development & Application

"Radically Rethinking Agriculture for the 21st Century"

Fedoroff [1] et. al. 2010. Science , Vol. 327. no. 5967, pp. 833 - 834

"What is needed is a serious reevaluation of the existing regulatory framework in the light of accumulated evidence and experience. An authoritative assessment of existing data on GM crop safety is timely and should encompass protein safety, gene stability, acute toxicity, composition, nutritional value, allergenicity, gene flow, and effects on nontarget organisms. This would establish a foundation for reducing the complexity of the regulatory process without affecting the integrity of the safety assessment. Such an evolution of the regulatory process in the United States would be a welcome precedent globally."

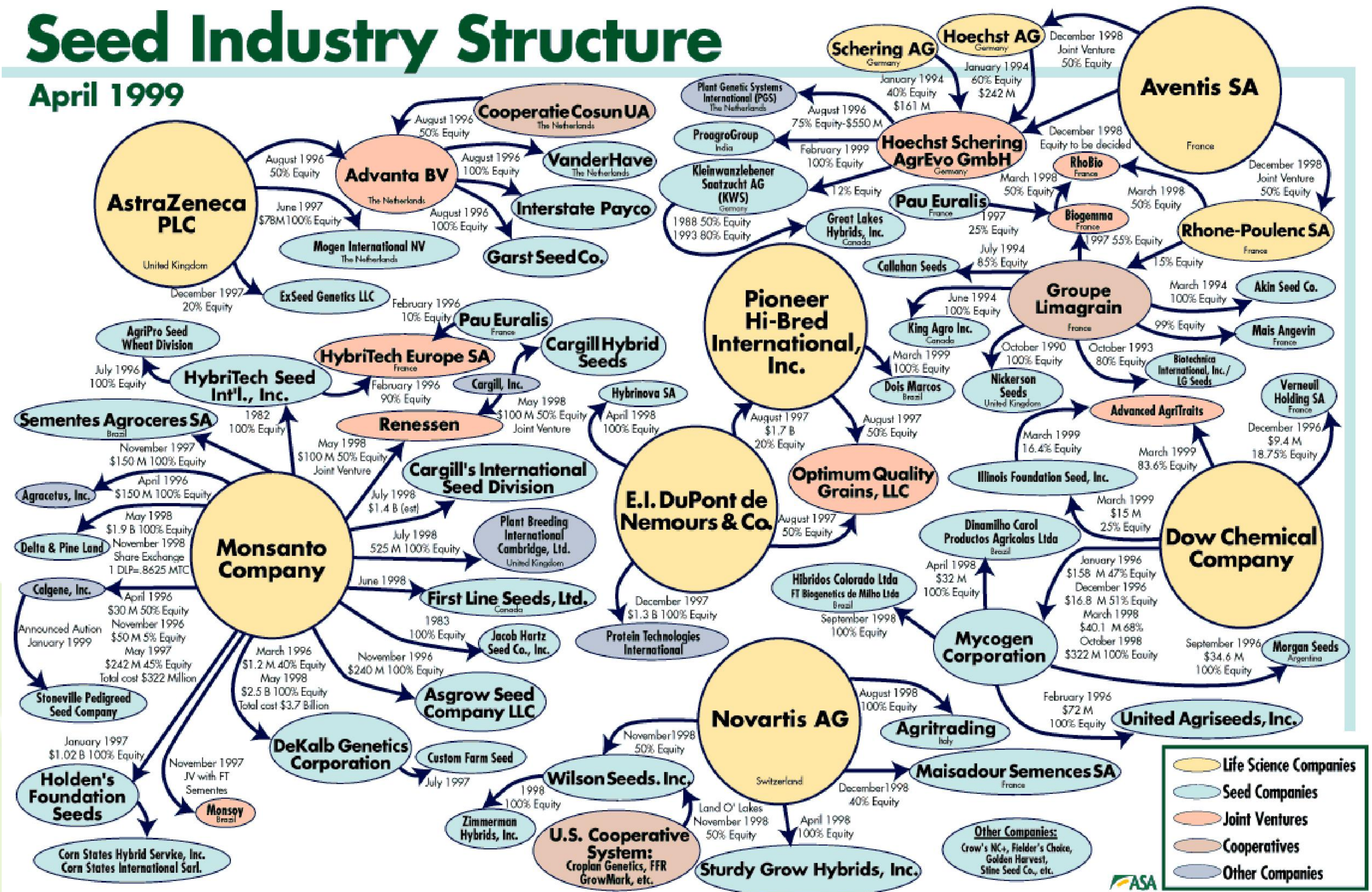
...

"It is also critically important to develop a public facility within the USDA with the mission of conducting the requisite safety testing of GM crops developed in the public sector. This would make it possible for university and other public-sector researchers to use contemporary molecular knowledge and techniques to improve local crops for farmers."

[1] Office of the Science and Technology Adviser to the Secretary of State and to the Administrator of USAID, U.S. Department of State, Washington, DC 20520, USA.

Adoption of GM Technology

Market Impacts



Adoption of GM Technology
Market Impacts

Vertical Integration

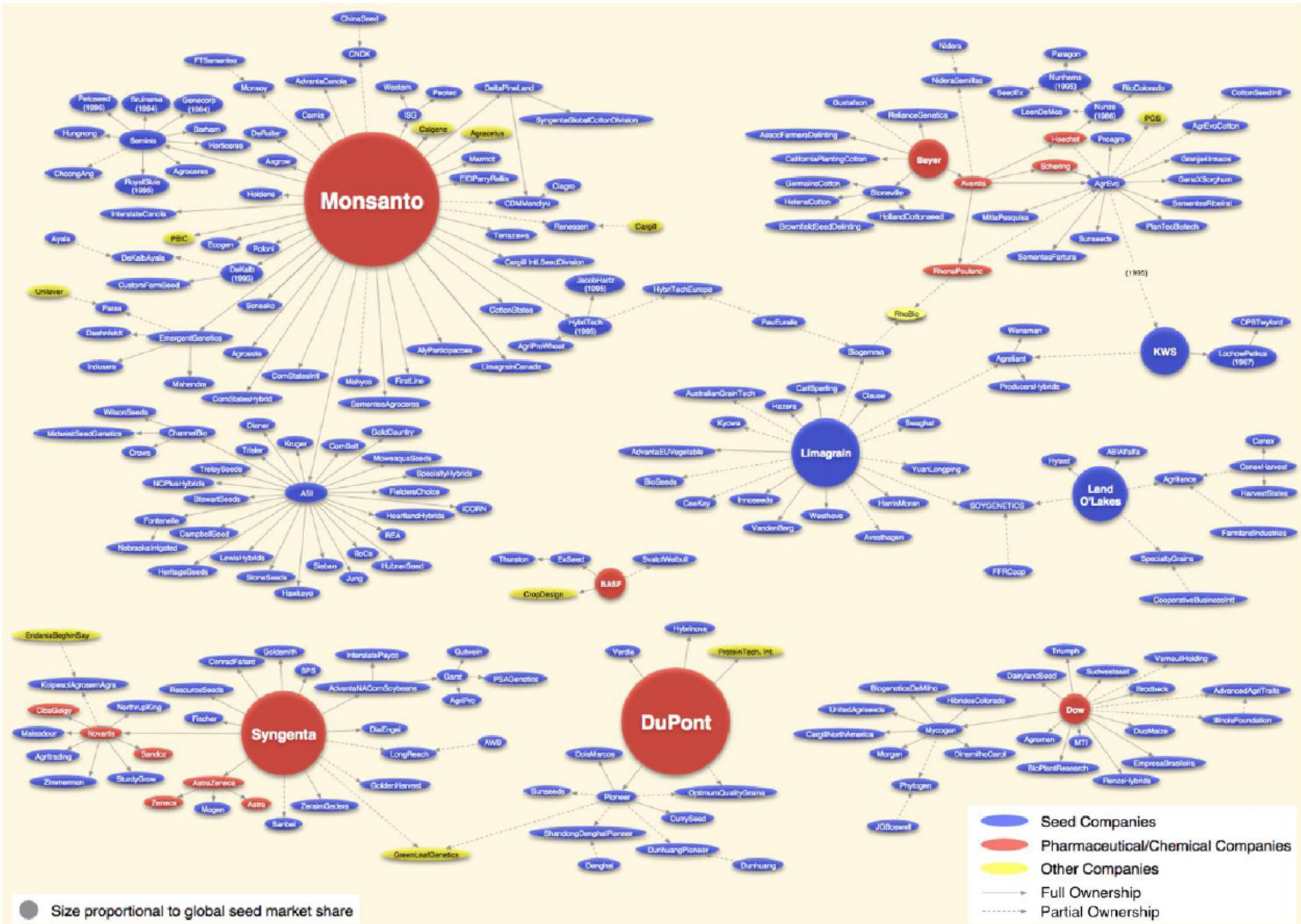
SEEDS – A GOOD PACKAGE FOR TECHNOLOGY
INPUTS - HERBICIDES
PROCESSING
DISTRIBUTION

MICROSOFT – MS Office Package

“EVERYTHING IN A BOX”

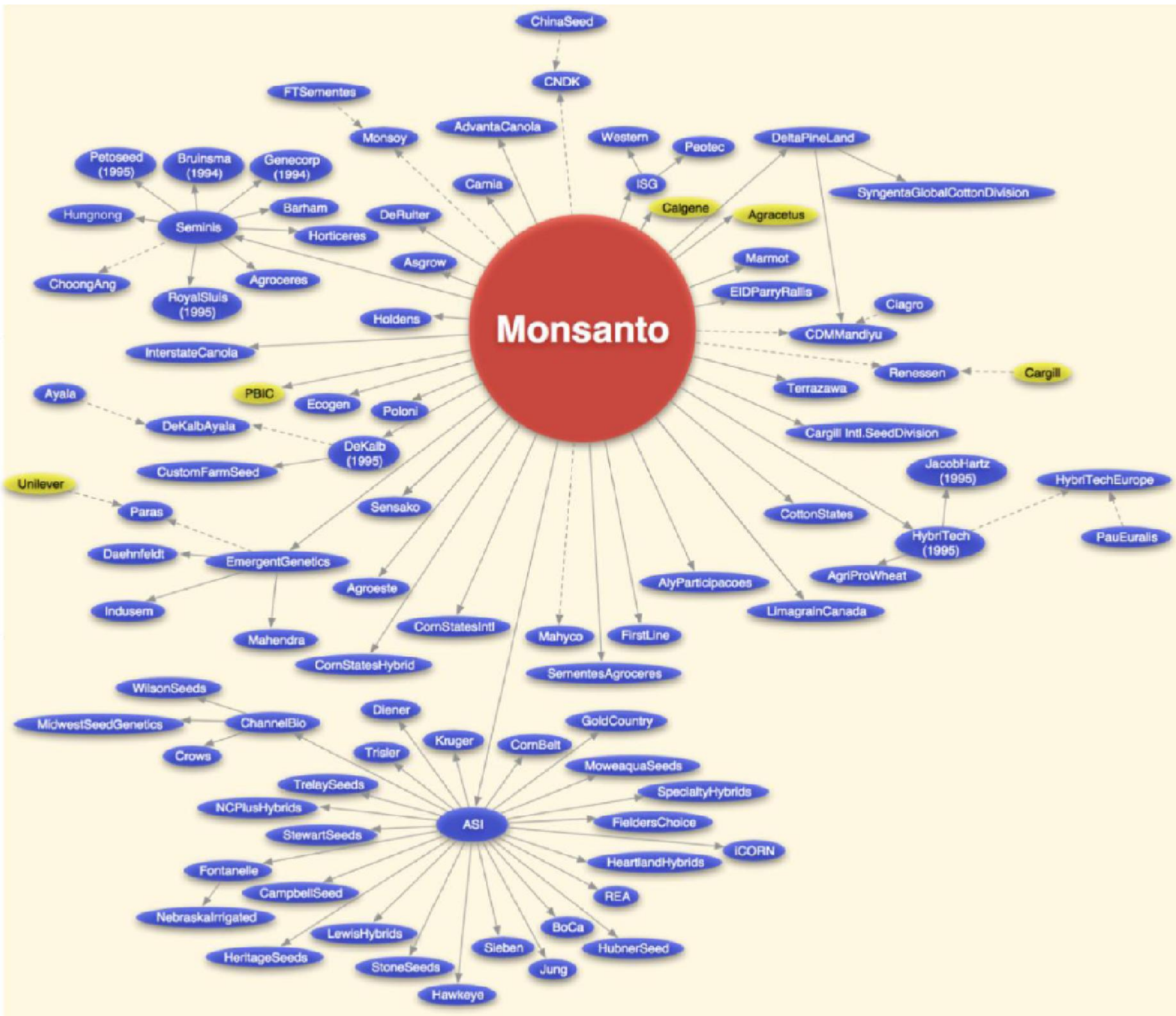
Adoption of GM Technology

Market Impacts – Seed Industry Structure – 1996-2008



Available at: http://www.mdpi.com/2071-1050/1/4/1266/pdf

Adoption of GM Technology
Market Impacts



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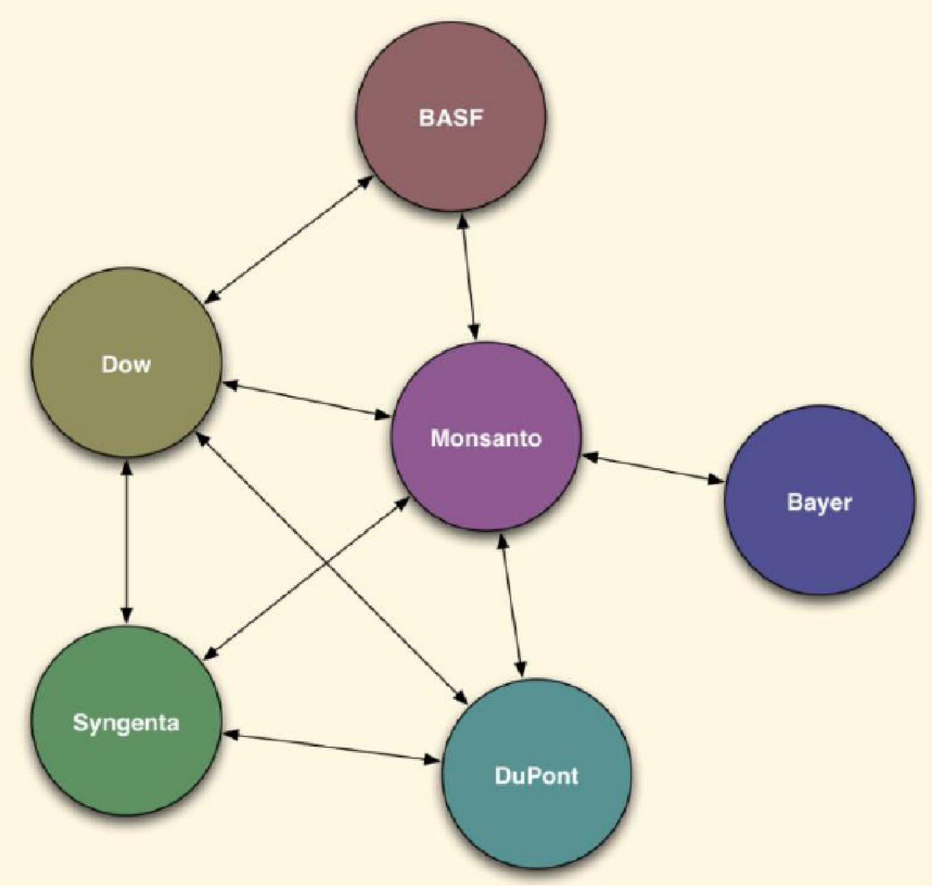
Adoption of GM Technology
Market Impacts

Cross-licensing

Cross-licensing agreements involving pharmaceutical/chemical companies for transgenic seed traits.
Monsanto has a central position in this network, as it is the only firm to have agreements with each of the other 5 firms.



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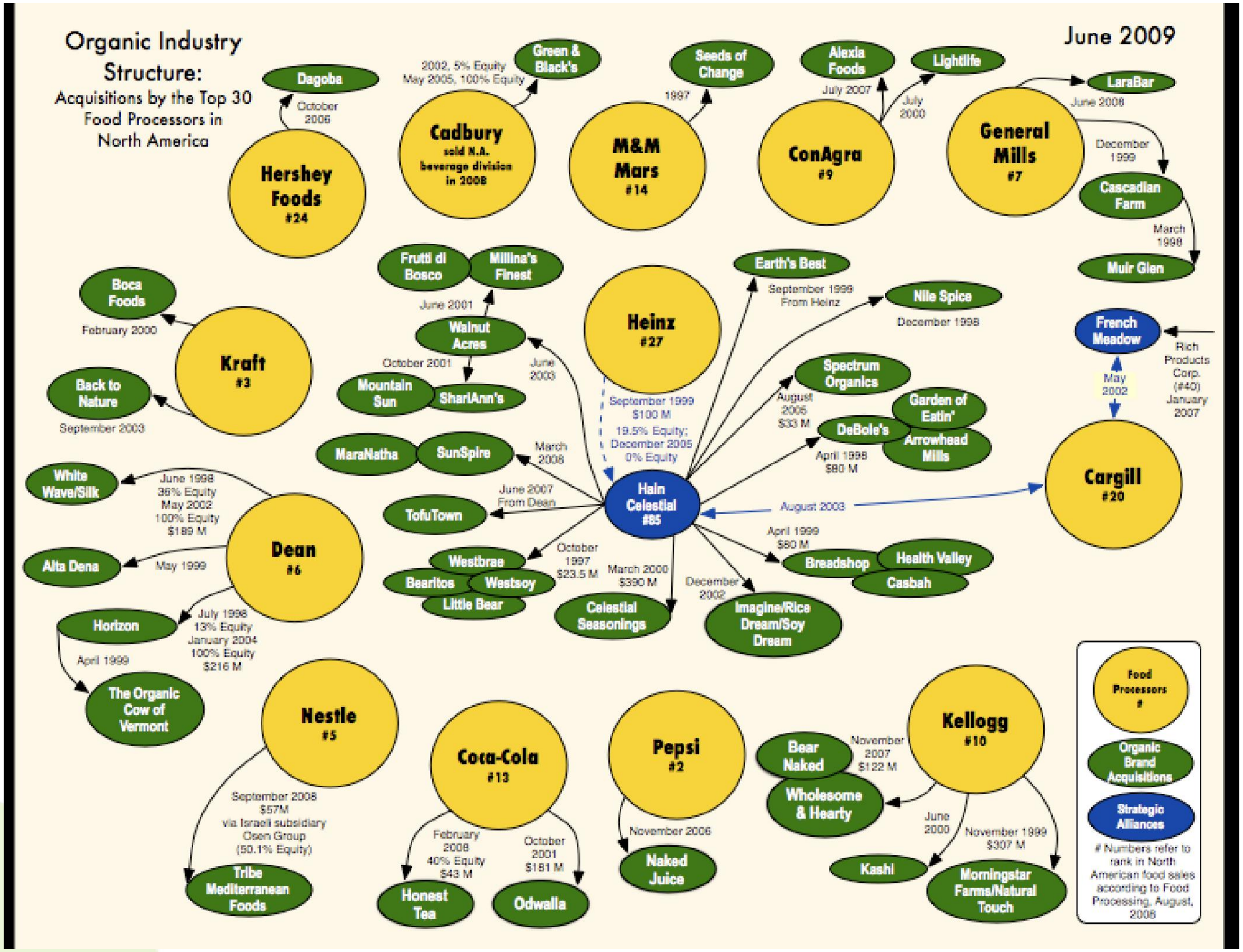
Organic Industry Structure



Howard, Philip H. 2009. *International Journal of Sociology of Agriculture and Food* 16(1), 13-30
Available at http://www.ijsaf.org/archive/16/1/howard.pdf

Foresight – Future Applications of GM Technology

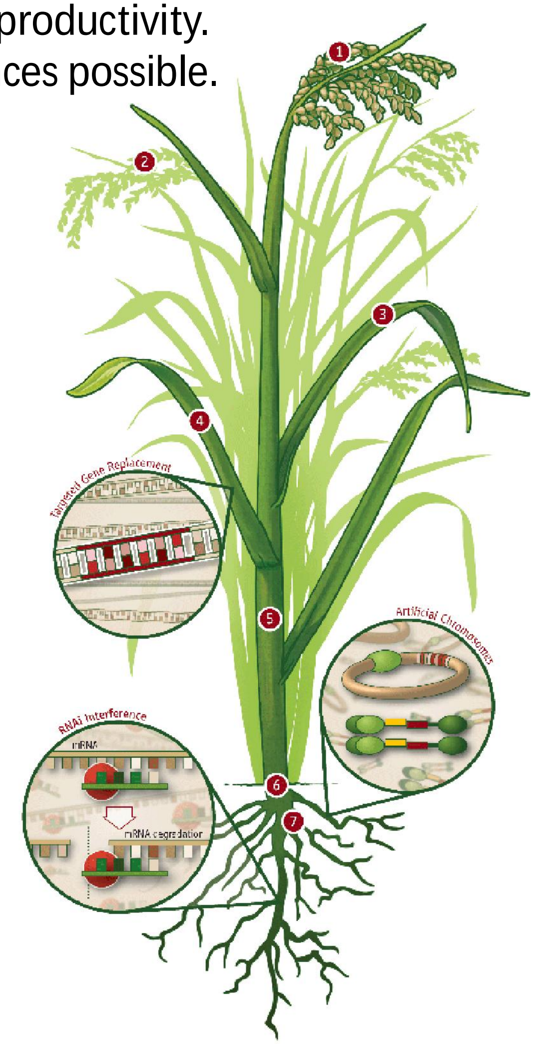
Examples of current and potential future applications of GM technology for crop genetic improvement.

Time scale	Target crop trait	Target crops
Current	Tolerance to broad-spectrum herbicide	Maize, soybean, oilseed brassica
	Resistance to chewing insect pests	Maize, cotton, oilseed brassica
Short-term (5–10 years)	Nutritional bio-fortification	Staple cereal crops, sweet potato
	Resistance to fungus and virus pathogens	Potato, wheat, rice, banana, fruits, vegetables
	Resistance to sucking insect pests	Rice, fruits, vegetables
	improved processing and storage	Wheat, potato, fruits, vegetables
	Drought tolerance	Staple cereal and tuber crops
Medium-term (10–20 years)	Salinity tolerance	Staple cereal and tuber crops
	Increased nitrogen-use efficiency	
	High-temperature tolerance	
Long-term (>20 years)	apomixis	Staple cereal and tuber crops
	Nitrogen fixation	
	Denitrification inhibitor production	
	Conversion to perennial habit	
	Increased photosynthetic efficiency	

Sources: Royal Society of London, *Reaping the Benefits: Science and the Sustainable Intensification of Global Agriculture* (Royal Society, London, 2009).
J. Gressel, Genetic Glass Ceilings (Johns Hopkins Univ. Press, Baltimore, 2008).

Foresight – Future Applications of GM Technology

Researchers' wish list includes traits that could boost plant productivity.
New technologies are needed to make some of these advances possible.



CREDITS (TOP TO BOTTOM): M. TWOMBLY/SCIENCE; ADAPTED FROM NSF; ADAPTED FROM CHROMOTIN, INC. AND WEICHANG YU ET AL., CURRENT OPINION IN BIOTECHNOLOGY 18, 2007; ADAPTED FROM ODEC

1.

Improve the nutrient content of seeds and edible plant parts.

For biofuels, the right mix of plant cell-wall components is needed to ease processing.

Source: Pennisi, 2010. Science Vol. 327. no. 5967, pp. 802 - 803

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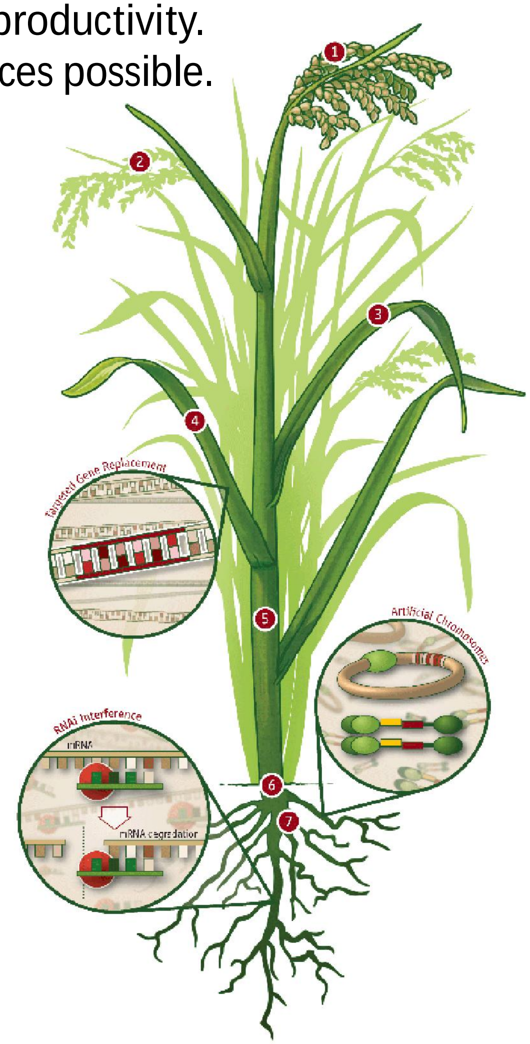
2.

No more sex. Hybrid seeds often produce more vigorous plants, but farmers can't always afford to buy new hybrid seeds.

Get hybrids to reproduce asexually through a process called apomixis.

Having apomixis in rice, for example, could save small farmers $4 billion a year. (An alternative to apomixis is to tweak the genetics of annual crop plants—which die each year—so that they become perennials.)



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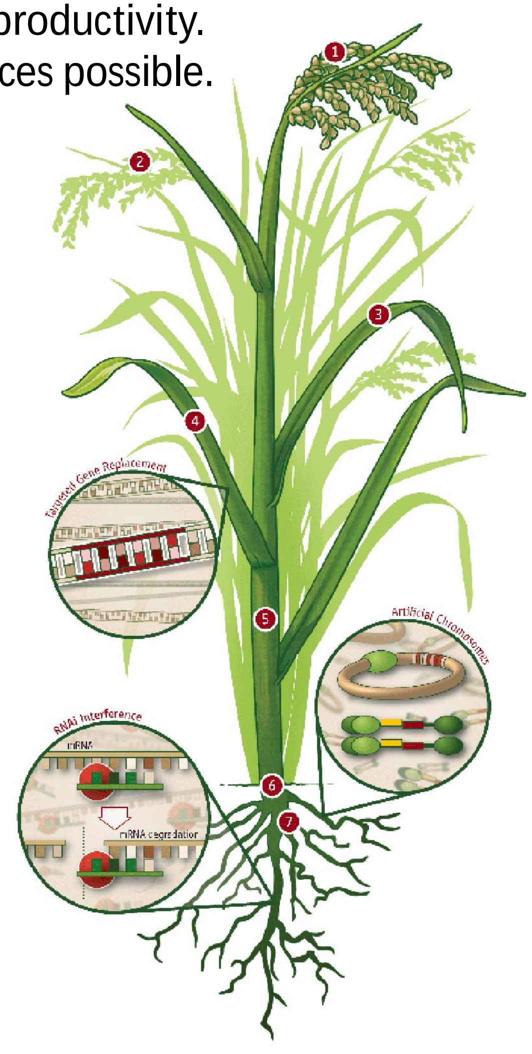

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3.

Install warning lights.

A pigment gene that turns on in times of stress could cause a crop's leaves or stems to change color—and alert farmers to take remedial action.

Source: Pennisi, 2010. Science Vol. 327. no. 5967, pp. 802 - 803

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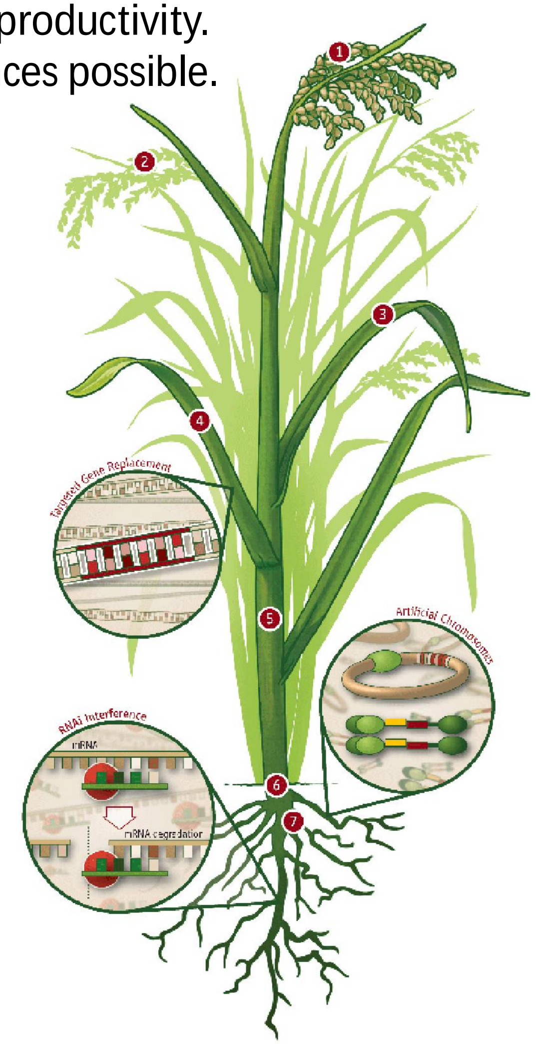
4.

More crop per drop.

Restructuring root and leaf architecture—and upgrading drought-response biochemical pathways—could increase water-use efficiency.

Shallower roots can better tap soil-surface moisture.



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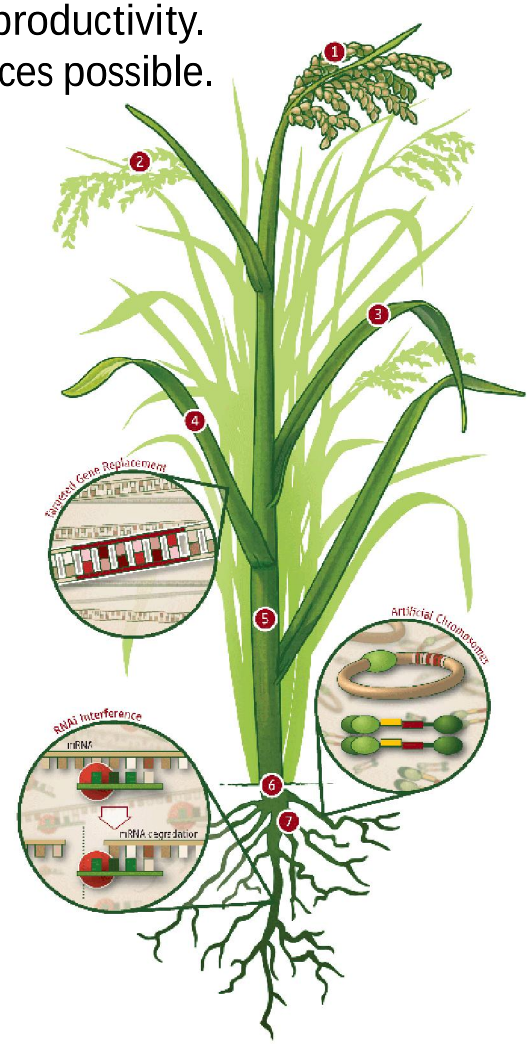

5.

Longer shelf life.

Enhanced control of ripening and senescence could reduce the amount of spoiled harvest.

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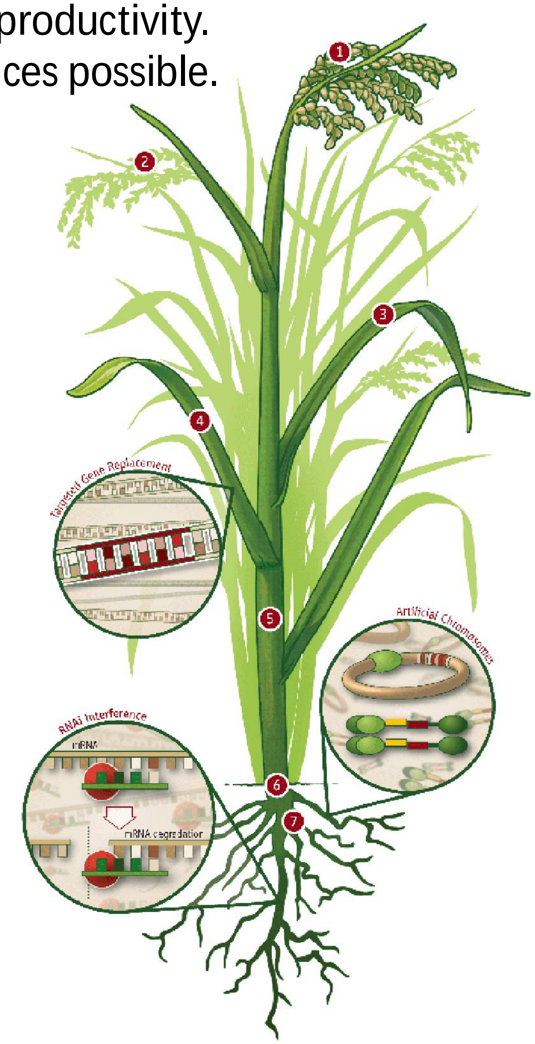
6.

Improve nitrogen efficiency.

Fertilizers are costly to farmers and the environment.

Improving a plant's uptake and use would be a big help.

Better yet, build into the plant the genes necessary to carry out nitrogen fixation.



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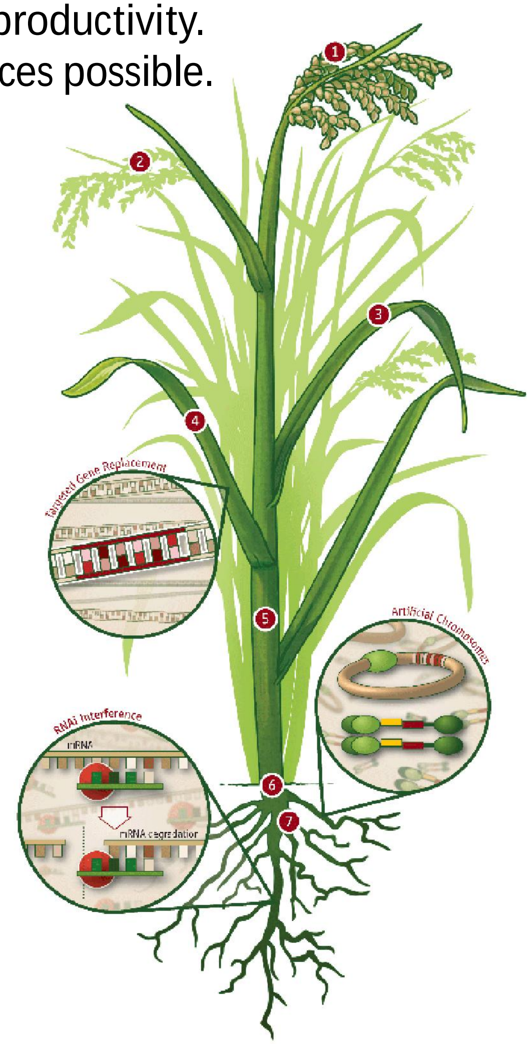

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7.

Tougher pest defenses.

Adding genes for toxins that kill only pest insects or nematodes

Addition of genes that attract the enemies of pests.

Source: Pennisi, 2010. Science Vol. 327. no. 5967, pp. 802 - 803

Foresight – Future Applications of GM Technology

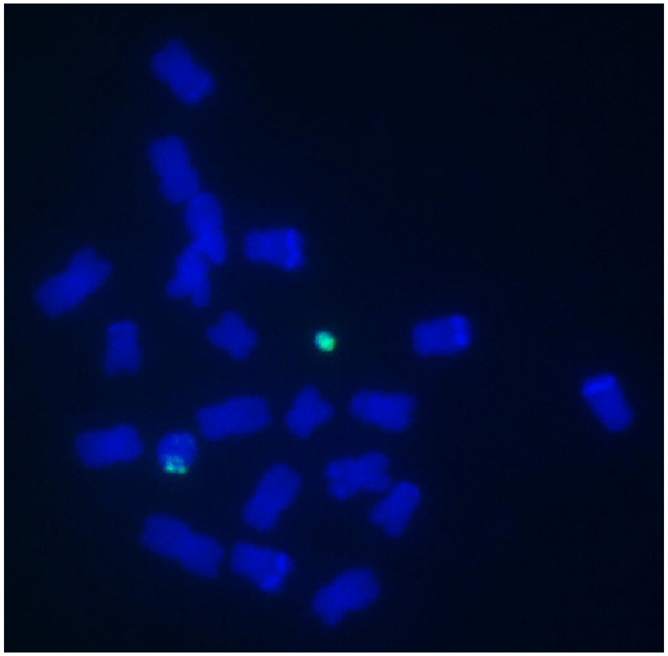
Artificial Chromosomes

If one gene is good, more genes are better. That's the mantra of plant biologists working to improve crops. Already, companies have engineered varieties that carry both herbicide and insect-resistance genes. Ultimately, researchers have set their sights on tweaking complex multigene processes, such as nitrogen fixation, which might involve 20 genes, or a special type of photosynthesis called C4 that works particularly well in tough conditions. Coordinating the expression of whole suites of genes, however, is an easier feat if the genes are grouped together. Here's where artificial chromosomes come into play.

Such "minichromosomes" come in several flavors. A company called Chromatin, for instance, has developed a way to attach useful suites of genes to a "platform" made from a ring of maize DNA. It encodes the repetitive regions of the centromere, the region near the middle of chromosomes that is important during DNA replication. Once loaded with the desired genes, the ring is put into the target plant.

Several teams are also making use of a plant's own "extra" DNA—such as the B chromosome in maize, or extra chromosomes in tetraploid versions of barley, rice, or Arabidopsis. They insert DNA containing the desired genes and the repetitive sequence of a telomere, which caps off chromosomes. That DNA inserts into the plant's chromosome and truncates it, creating a new minichromosome.

These techniques are promising, but it's not clear how stable the minichromosomes will be over multiple generations—or if the right amount of gene expression will be maintained over time.



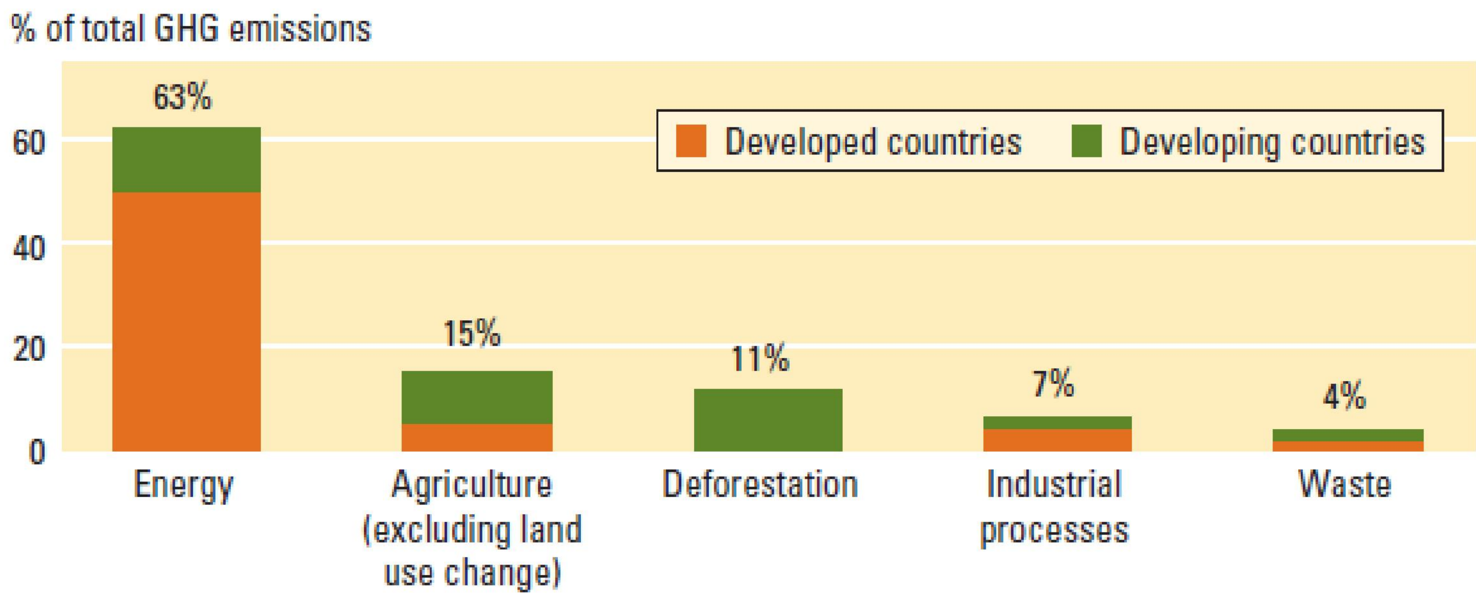
The isolated green dot marks the centromere of a minichromosome.

CREDIT: RICK E. MASONBRINK AND JAMES BIRCHLER

Source: Pennisi, 2010. Science Vol. 327. no. 5967, pp. 802 - 803

Vulnerabilities

Agriculture and deforestation are heavy contributors to greenhouse gas emissions



Source: WDR 2008 team, based on data from the United Nations Framework Convention on Climate Change, www.unfccc.int.

Sustainability of Modern Agriculture...

Great gains from agricultural innovation... but with significant side effects.

Source: Embrapa

Sustainability of Modern Agriculture...

Great gains from agricultural innovation... but with significant side effects.

- soil erosion
- soil structure decline
- nutrient loss
- acidification
- salinity
- biodiversity decline
- weed infestation
- eutrophication of waterways

To be continued…